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Vol. VI, No. 5 Sept.—Oct. 1955

Official Publication of the American Institute of Industrial Engineers, Inc.

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THE JOURNAL OF
Industrial Engineering

OFFICIAL PUBLICATION OF
THE AMERICAN INSTITUTE OF INDUSTRIAL ENGINEERS, INC.

Published Bi-monthly

Editorial and Publication Offices—A. French Building, 225 North Avenue, N.W., Atlanta, Georgia

AIIE Headquarters Offices, 145 North High Street, Columbus 15, Ohio

Application for second-class mail privileges is pending at Columbus, Ohio

VOL. VI *September-October, 1955* NO. 5

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SUBSCRIPTION PRICES: $3, one year; $5, two years; single issues, $.75. Effective January 1, 1956: $6, one year; $10, two years; single issues, $1.50.

ALL MANUSCRIPTS for review should be submitted with drawings suitable for reproduction to the Editor-in-Chief, Journal of Industrial Engineering, A. French Building, 225 North Avenue, N.W., Atlanta, Georgia.

ADVERTISING RATES available from the Advertising Manager or any Editorial Board member. Send copy and cuts to the Advertising Manager, A. French Building, 225 North Avenue, N.W., Atlanta, Georgia. Final due dates for copy: Nov.-Dec. issue, Sept. 15; Jan.-Feb. issue, Nov. 15; Mar.-Apr. issue, Jan. 15; May-June issue, Mar. 15.

ALL READER COMMENTS material should be submitted to the Editor-in-Chief. Limit individual comments to 400 words.

RECENT READABLES material should be sent to the Editor, George L. Anton, Manufacturing Dept., Ethyl Corp., P. O. Box 341, Baton Rouge 1, Louisiana. Limit each review to a brief discussion of the contents of the publication.

PRESIDENT'S MESSAGE

A Challenge & Responsibility

By E. L. Slagle

President, American Institute of Industrial Engineers, Inc.

Those of us who attended the Sixth Annual Conference of the American Institute of Industrial Engineers were impressed with two things: (1) the capable manner in which the conference was handled by the General Co-Chairmen, Joseph Movshin and Gerald Nadler, and their committee; and (2) the growth rate of our organization. In seven short years we have grown to 48 senior chapters, 25 student chapters, and over 4,000 members (3,060 senior and associate members, 110 affiliates, and 930 student members).

In my last message, the need for well-planned, properly publicized activity was emphasized; in addition the point was made that certain activities require more immediate attention. Now we must turn our attention to the more mundane matter of finances. The budget for the coming year involves dipping into our reserve funds even though we are not planning to operate in a manner fully consistent with our objectives. To say it another way, our income will not sustain our operation in a manner which is in keeping with our professional status and which meets the needs of our membership. We are running out of gas and must: take immediate stop-gap steps to remedy the situation; and establish a long-range financial plan involving a study of membership growth and the probable budget requirements in the areas of activity now dormant or functioning with minimum progress due to lack of funds.

There are three matters which are of immediate concern to us:

(1) operation of the national office;
(2) an improved and enlarged Journal; and
(3) industrial engineering research.

The monetary needs of these items have been most carefully reviewed during the past year. The minimum expenditure required to properly implement corrective actions would result in expenditures in excess of income of approximately $11,000 in 1955–56, and approximately $16,000 in 1956–57. Since our total bank balance as of April 30, 1955, was only a trifle over $8,400, it is apparent that, for the immediate future, we must proceed on some interim, compromise basis. At the next convention I hope to be able to report to you that we are on sounder financial ground, and that our programs are no longer restricted by our inability to finance them. Perhaps it would be in order to take a closer look at the three items of immediate concern mentioned above.

First, the need for a national office capable of operating with only the direction offered by the Executive Committee at its monthly meetings, and capable of representing us in a manner consistent with our professional status. Our Columbus office has always depended upon our Executive Secretary and the Assistant Executive Secretary for supervision. On a day-to-day basis the office has been handled by an Office Manager in charge of routine correspondence clerical and stenographic work. In addition to the Office Manager, we have a stenographic force consisting of one employee full-time and occasional part-time employees as required to meet peak workload demands. Our Executive Secretaries have had to spend a considerable amount of time away from their regular jobs, and on their weekends, providing necessary supervision and ensuring that all actions were consistent with the constitution and in keeping with Executive Committee instructions.

Thus, we have sorely imposed upon such individuals as Joe Southern and Steve Veirs, and we have relied heavily upon the broad-minded attitude adopted by their respective companies. The national office workload has increased to such a point that our Office Manager has resigned due to excessive pressure and to the lack of daily supervision. Both Joe and Steve cannot continue to spend the amount of time at the national office that they have in the past. There is not sufficient money in the budget to allow for the employment of a full-time Executive Secretary. We cannot operate with part-time direction in the office, since: (1) there would be too many conflicting demands with the other job or jobs; (2) the increased volume of work and the many daily decisions require full-time attention; and (3) the stenographic force must have on-the-job supervision. As an interim arrangement, we have hired a Business Administrator capable of running the office with a minimum of supervision from our Executive Secretary and his assistant. This mode of operation will provide a definite improvement and should see us through to the day that we can employ a full-time Executive Secretary of high reputation and of recognized stature in our profession.

The second of the three items pertains to our Journal. During the course of the convention, it was forcefully brought to my attention by many individuals and in various committee meetings that the Journal requires improvement. Recommended changes involve size, format, content, etc. All criticisms have as their origin our budget allocation which has restricted the growth of the Journal. We are all aware that we are receiving more than our money's worth since all the work except actual printing is done free of charge. We have Frank Groseclose, Bob Lehrer, and their colleagues to thank for this arrangement. The general quality and size of this publication is, therefore, limited only by the money budgeted for printing and incidental expenses. We will continue to benefit from the free help so generously given by our friends at Georgia Institute of Technology. Here, too, we have taken a halfway measure to correct the situation. Eventually, we must provide our profession with a publication which compares favorably with those published by other professional societies.

The third item, research, represents a responsiblity which our organization must assume, and assume quickly. The ever-increasing complexity of management problems will not permit haphazard improvement of the techniques designed to handle them. Every profession must find a way to foster research within its sphere of interest—or atrophy. It is not planned that we will engage in research as such. It is necessary, however, that we encourage such endeavors by providing necessary incentives and even, in the future perhaps, monetary grants to support adequate investigations. The program designed to fit this need was presented by our Director of Research, Andrew Schultz, at the Board of Trustees Meeting in St. Louis on May 13, 1955. This program will be presented in greater detail in a future issue of the Journal. In the long run, we hope to have this program on a self-sustaining basis. Initially, however, we must draw on our income for this purpose.

We have reached a point where we, as representatives of the industrial engineering profession, must either step up or step down. To avoid the latter course, we must expand our income to a level in keeping with our needs and responsibilities. Possible sources of revenue have been given very serious study. Cost increases accompanying the addition of new members absorb the major portion of the national dues—expanded membership will not solve the basic problem. The other avenues, leading toward improved financial condition, which have been suggested and explored are:

1. Increased dues or initiation fee;
2. Participation by the national in regional (not local) conferences and conventions;
3. Journal advertising and consolidation of the News Letter with the Journal;
4. Company memberships;
5. Industrial grants supporting our programs;
6. Donations by individual members; and
7. Life memberships.

I am aware that it will be difficult to find a popular solution to our money problems. The unhappiness which can result from solutions designed to improve our financial condition was brought to my attention rather strongly when I first discussed these matters with your chapter presidents and representatives in St. Louis last May. However, I am not counting on popular appeal, but rather upon a mutual recognition of the problem combined with a desire to help ourselves with a constructive solution. Let us examine in more detail some of the proposed solutions:

1. Increased dues or initiation fee.

Dues and the initiation fee were initially established at a very low level. We are still below the rates charged by other national professional organizations. An increase is a logical step.

While on the subject of dues, perhaps it is in order to review a problem which has given many chapters some concern—the handling of transfers from associate to senior membership. This matter has been discussed on many occasions, and so far as your national officers know, the problem could only have been handled by the chapter working with its members owing to our dues collection procedure as established by our by-laws. Neither national nor chapter officers can be aware of the change in qualifications of the members. Some national organizations overcome the difficulty by placing in effect a schedule of dues rates directly associated with the age of the member. This method, which has the advantages of impartiality and ease of administration, was adopted by the Board of Trustees at the May meeting in St. Louis.

2. Participation by the national in regional (not local) conferences and conventions.

Last year three such conferences were held. They were well-organized, very successful affairs, and all members of the American Institute of Industrial Engineers are indebted to the individuals responsible for the substantial contribution thus made to the attainment of our objectives.

We now have six regions. It follows that we will soon have six regional conferences and one national convention each year. We are headed for difficulties with conflicting dates, program problems, and mistakes which will naturally ensue due to the large number of meetings and to the lack of experience by many chapters

in sponsoring such meetings. I have checked with four national professional organizations to learn their point of view, or approach, to this situation. In all four cases, the national organization retained policy control over content, convention or conference date, and financial responsibility (sharing the profit or loss). In some cases, the national organization assisted in the matters of programs and correspondence. It seems reasonable to me that we should work toward this type of operation. I also believe, however, that chapters should be left on their own so far as local conferences are concerned.

3. Journal advertising and consolidation of the News Letter with the Journal.

The Journal staff has actively solicited advertising. Continued intensive effort will be made in this direction. We anticipate that, at best, we could earn no more than a small portion of the Journal budget in this manner.

By consolidation of the News Letter with the Journal, the Journal will be able to provide the necessary News Letter service while reducing total workload and effecting a budget reduction of between $500 and $1,000 annually.

4. Company memberships.

Many members have suggested company memberships in our organization. Although company memberships could, no doubt, be obtained, there are good reasons for not seeking them. The most compelling reason is that our affiliation with the Engineers Joint Council precludes such action since company memberships are not permissible under the E. J. C. constitution.

5. Industrial grants supporting our programs.

This suggestion has many vociferous proponents and many equally vociferous opponents. Many of those who oppose the action are receptive to the idea if we proceed on the basis of clearly earmarking all such funds, and if we seek such grants only for the period of time required to place our programs on a self-sustaining basis.

Some of the above methods of improving our financial situation will go into effect this year; some will go into effect later; some will never be utilized. I sincerely hope that I can count on you for an understanding of the situation and for support of the programs designed to help our organization. It is always difficult to find a solution to a problem which each and every member will find satisfactory. Engineers by nature are individuals of high principle and loathe to accept the idea of "regimentation". You may be sure that your national officers are trying to regiment no one. We are simply striving for a strong, well-organized institute of proper stature and prestige, which will provide this country with industrial engineers of ever-improving quality.

One last thought—national officers, by custom, remain in office only one year and, therefore, are not seeking political reward. In addition, the financial burden carried by these officers is not shared (except to a small degree) by the American Institute of Industrial Engineers. Furthermore, all national officers are active members of a chapter of the American Institute of Industrial Engineers. Since we have no political or financial motivation, and since we are acutely aware of the impact that actions of the national officers can have on both the individual member and the operation of the chapters, you can be very sure that all actions fully and fairly take into consideration all points of view and that all actions are designed to benefit our organization as a whole.

Rockwell's Philosophy of Industrial Engineering

By W. F. Rockwell, Jr.

President, Rockwell Manufacturing Company

The dictionary tells us that a philosophy is a body of principles which underlies a given branch of man's activity. The body of principles which forms our philosophy of industrial management is an outgrowth of our experience during the past three decades. Our industrial engineering philosophy is directly related to our overall industrial philosophy.

It is difficult to extract an individual philosophy for any given function within our organization from this over-all philosophy. It is doubly difficult to set aside a group of principles from our industrial philosophy and say, "This is our philosophy of industrial engineering."

Our outlook on industrial engineering, however, is different from our outlook on product engineering or other strictly quantitative branches of industrial endeavor. The very nature of industrial engineering places an emphasis on the qualitative nature of the work. To me, industrial engineering is the application of scientific principles and engineering methods to problems of planning, operation and control of industrial work.

In all three we come into contact not only with measurable quantities such as machines but, mainly, with the most imponderable element of industry—people. But, whether it's people or "things" we're dealing with, industrial engineering is helping us make thoroughly calculated decisions today instead of the rule-of-thumb decisions of three decades ago.

Rockwell's Industrial Philosophy

Because our overall industrial philosophy is the foundation of our industrial engineering thinking, it seems only logical to begin by briefly outlining this larger philosophy:

The basic concept is this: Planned diversification is the surest path to corporate security.

When I speak of security, I do not mean a complete removal of all the normal fluctuations by which we could

either profit or lose. Our ultimate goal is not consolidation to a point where we are satisfied with a minor insured return. Our desire has been to provide, by means of a balance of manufacturing facilities and products, an optimum of protection for our gains made through individual initiative.

In short—diversity! Diversity in industry gives us the desired security and allows us the opportunity to use our individual talent and ingenuity to benefit from normal risk investment of our capital. Long experience indicates that no one can diversify thoroughly enough to provide the desired security while still remaining in one industry, under one roof, or in one locality.

Diversification, as we use the idea, does not mean decentralization of one product in a variety of locations. We have succeeded in building a company composed of a variety of products in a variety of locations. However, the diversity of our operation is not an across-the-board scattering of products. We have used a set policy of acquisition for expanding facilities or adding new lines of products.

Briefly, the policy is this:

1. We are not interested in liquidation operations—but only sound companies that can contribute over the long pull.

2. We are interested primarily in companies in the producer durable field.

3. We seek companies adaptable to the skills and experience of our present management and our technical, manufacturing and distribution staffs.

How Much Decentralization?

In the process of diversifying, many facts have become apparent to us: We know that most of our managerial problems are simpler in plants employing 500 or fewer. We are beginning to think the ideal size may be between 300 and 400 employees. We feel that human problems in management disappear with direct contact.

In practice, every plant manager, division manager, and sales manager operates much as if he were running his own business. Records are kept in such a manner that it is easy for the individual manager, and for top management, to see his effectiveness or lack of it. To each of these men, the product on which his personal success depends is the most important product in the world. He won't let it become unimportant to us.

A manager, if allowed to run his facilities as his own with as little direct control from a centralized location as is practical, will accept the responsibility for his personal organization and will thus provide the basic unit on which to build the best possible profit organization. A group of these small successfully managed units provides a secure and financially strong corporation.

On the other hand, with an organization made up of 15 such plants, some centralized services will be helpful—some control essential. We believe, for example, that centralization of money, advertising, accounting, tax, labor and legal advice, industrial and public relations, new product engineering, and industrial engineering provide immeasurable opportunities for the individual manager to secure specialized help in any phase of industrial management.

In other words, we provide from a centralized source various services which isolated manufacturing units of from 300 to 500 production workers could not economically provide for themselves.

In centralizing certain functions within our industrial organization, however, we have experienced an oscillating reaction. Centralization often tends to draw in too much direct control into the centralized source. This, of course, results in a tendency among division personnel to look continually to the centralized source for decisions of a nature that could be better made at the division level.

As a remedy for this situation, we naturally reverse the centralization trend in some areas. If this remedial decentralization goes too far, however, the result is poor communications and lack of the coordination necessary for a successful multi-plant operation. The next step, of course, is renewed emphasis on centralization.

Role of Industrial Engineering

How does all this affect our industrial engineering practices and policies?

Actually, we feel that these centralization cycles have helped us build a soundly operated industrial engineering organization tailored exactly to fit our overall corporate pattern.

We have two separate industrial engineering entities: (1) a headquarters industrial engineering staff and (2) separate industrial engineering units at each manufacturing location.

This naturally is in line with our general policy of having direct control of the routine functions in each manufacturing location under the general manager, who is responsible for the profit of that unit. The divisional industrial engineering department reports directly to him and receives instructions from him.

Our headquarters industrial engineering staff—again in line with our general policy—standardizes general procedures and policies for industrial engineering departments in all divisions. This includes:

1. Labor standards for:
   a. wage incentives
   b. cost estimating
2. Job evaluation
3. Plant layout and material handling
4. Methods analysis
5. Selection of equipment
6. Revision of expenditures for capital equipment
7. Indirect cost analysis
8. Establishing and analyzing labor control reports

Through this type of centralization, we have given the general manager and his plant industrial engineer relative freedom of operation within the bounds set by our overall policies. The division engineer must work within these bounds but at any time may request that policies be modified to meet circumstances existing at his individual location.

Position and 'Backing' Count

Our company has learned that the effectiveness of an industrial engineering department—either staff or division—is in direct proportion to:

1. Its organizational position in the operation.
2. The executive backing it receives.
3. The breadth or scope of functions assigned to it.

We have learned that the industrial engineering department, in order to function effectively, must be placed, organization-wise, under the executive with the major direct authority. Accordingly, the heads of our divisional industrial engineering departments report directly to the top executives of their respective plants or divisions; and the chief industrial engineer, who heads the industrial engineering staff, reports directly to me.

When speaking of backing for industrial engineers, or, for that matter, for any function within our industrial organization, we must consider the confidence that function builds by the results it shows top management. Backing for any industrial function is a growth process resulting from the selling of ideas and the effective results of those ideas.

It is a foregone conclusion that industrial engineering cannot be effective without backing. To receive it the industrial engineer must build management confidence through successful installation of new ideas and techniques. In any plant or facility the backing or authority of industrial engineering will grow with the effectiveness of the work it does.

The existence of this growth process may not be recognized by a relative newcomer and, consequently, may offer an early pitfall for many potentially good industrial engineering departments. So often a relatively new industrial engineering department will attempt to apply a function or technique before the proper growth cycle, or state of readiness of management, has been reached.

This state of readiness is in the hands of the industrial engineer himself: Has he sold management sound, productive ideas, then followed through with results? Corporation executives are human. They are subject to all the influences and pressures which are inherent in human nature. They like to be sold. They also like to realize, after handling the product a while, that the purchase has been a good one—that their judgment has been sound.

Very few people in industrial management today believe in magic. Industrial engineers must realize that many of the new management techniques and their results appear to border on the fantastic when presented to people who are not familiar with the historical groundwork which led to them—regardless of the amount of supporting source material presented with them.

Selling 'Down the Line'

The natural conservatism of these human beings can only be broken down by a constant process of selling and results. Selling not only to executives but also to operating personnel all down the line. Too many industrial engineers, after working hard and successfully to sell an idea to the "boss," will then make the mistake of feeling that this is all that is necessary to win the authority to force their ideas into acceptance.

No executive can successfully legislate ideas into his operating personnel. Selling an idea to the boss only gives the industrial engineer the authority to continue to sell the idea to the operating personnel with executive approval.

What we consider backing in our organization is for our managers, or myself, to help the industrial engineer sell the idea to the operating personnel. This selling on the part of the boss should take two forms:

First, on acceptance of the merit of a program, technique or idea, the executive should make his acceptance known to all concerned. He can do this formally or informally depending on the individual circumstance.

Secondly, the executive should follow the progress either personally or in report form and aid the industrial engineer in re-selling his job if progress is stymied through non-acceptance by operating personnel.

Scope of Industrial Engineering

The true scope of industrial engineering is indicated by its definition as "the application of scientific principles and engineering methods to management problems."

However, the old saying, "a workman is known by his tools," holds true in most cases—and too often in the past, industrial engineers have become too closely associated with the tool of work measurement. Management people in general tend to think of time study and other forms of work measurement as an end in themselves—rather than as tools for the achievement of industrial engineering's real ends.

Industrial engineering has progressed tremendously in the past few decades. It should no longer be thought of in terms of stop watches and slide rules. The overall aspect of the profession should not be judged by its individual tools—such as time study, work simplification and cost estimating.

Management problems all come under the heading of planning, function or control. If an industrial engineering department is not in use in all three of these areas, it is not being fully utilized—particularly any place where cost reduction can increase profit.

When I speak of cost reduction to increase profit, I should define the term. Many management men, whenever they become aware that business and competitive conditions are getting stiffer, begin pulling in their heads and slashing indiscriminately at costs. They call this cost reduction.

Such a definition is one with which the Rockwell organization does not agree. Our ultimate goal is obtaining the maximum return for each dollar we have invested. We do not wish to decrease in any way the amount of money which we invest in our production facilities. The indiscriminate slashing of costs is an indiscriminate reduction in the amount of money we have invested.

What we mean by cost reduction is an effort to assure ourselves that each dollar we have invested in our manufacturing processes is providing us with a maximum return.

'Organized' Cost Reduction

Cost reduction should be organized logically with the ultimate goal of increasing our investment and the return per dollar on that investment. A typical example of our thinking on cost reduction is an extensive program now under way in our plants to replace obsoleted machinery with machinery designed to reduce our unit cost. In this manner, we can make the purchase of our products more attractive to our customers.

Another example of our concept of cost reduction:

When business conditions become more competitive, customer orders come in for smaller quantities of our product while the number of such orders often increases. In the old days, this naturally added to the work of our order department. Naturally, too, an arbitrary slash in the cost of operating this department—made in line with the sales drop—always resulted in poorer service to the customer at a time when it was most important to the profit picture to give him the best possible service.

To alleviate this situation, we have recently installed some of the world's most modern electronic equipment to process customer orders. This not only has provided faster order service but has also eliminated a great proportion of the labor cost which was required with our old customer order system.

Both the new production equipment and the new order processing facilities described above illustrate how our overall company-wide profits are increased not by slashing away at the present costs but by spending or investing money to improve our processes.

All expenditures which are made for the operation of a manufacturing facility should be made on an economic basis the same way we analyze a piece of capital equipment. They should not be considered from the standpoint of minimum cost, as such, and not from the basis of any arbitrary ratio, but rather from the standpoint of how much they contribute to the profits of the company.

Cost Is the Keynote

All manufacturing problems have something to do with cost in a very broad general sense. Industrial engineering, in its broadest aspect, *is* cost reduction. Industrial engineering functions most effectively when applying scientific principles and engineering methods to the expenditure of money.

The best results can be obtained from the industrial engineering department when it is given a broad functional responsibility in the planning phases of manufacturing operations. Our experience has shown that careful planning of manufacturing facilities—planning involving thorough plant design and layout work, material handling studies and engineered processing methods—can provide maximum profits for each dollar invested.

For example: an article in a recent issue of *Flow Magazine* about one of the larger corporations in the country today stated: "Expansion plans are under way by Company X even though the company's recently completed 150,000 sq. ft. structure has been occupied only a few months. A contract for a 60,000 sq. ft. expansion has been let."

To the uninitiated, this may sound as if business is booming. To the enlightened executive and the plant layout engineer, however, it means only one thing: lack of planning and foresight when the original drawings were on the board. Past experience indicates that the cost of adding the extra 60,000 sq. ft. now will be much higher than the cost would have been had the larger structure been built as a single unit.

A few years ago, when erecting a plant addition, another leading company made the mistake of completing specifications for the building and of starting construction work before a machinery analysis had been completed. On completion of the building, it was found that the material-handling equipment required 3 more feet of head room than had been provided for. This necessitated a second-choice material-handling system and will probably, over a period of years, cost the company many times more than the additional 3 feet of head room would have.

Another instance of a cost reduction this same company could have made through preplanning came to light when one of its plants received an unfavorable rating by fire underwriters owing to insufficient explosion-type sash in a new paint storage addition. This could have been avoided by a proper analysis of the addition by an industrial engineering department prior to construction.

In order to eliminate such planning errors, which ultimately result in increased costs, we have all new facilities planned by a team of engineers. This team consists of a registered architect, who is one of our corporation executives, a staff industrial engineer, an electrical engineer and a member of line management who is directly responsible for the facility under consideration. This pooling of skills in our team effort results in better planning and tremendous potential cost reductions.

Methods Important

One subject of special interest to us is methods. We do not believe any other phase of industrial engineering can contribute more to profits than a well organized and well coordinated program of sound methods engineering. Many companies, however, fail to take advantage of the tremendous potential savings possible through methods work.

During the past few years, we have been going through a period of evolution in our thinking about methods. There was a time when product design was solely the function of the foreman and line people. However, because of technological advances and the need for more competitive designs, this function gradually became the responsibility of the product design engineers.

Today with the increasing number of technical processes, the many alternate methods, the advancements in metal removal, etc., it is coming to be recognized more and more that it is just as necessary to apply sound engineering to methods as to product design. Improvements in operating methods are particularly important from a cost reduction standpoint because of the double-barreled effect they generally have on costs.

For example, where operations are combined, we not only obtain the advantage of cost reduction in direct labor

but also obtain other indirect savings which can be as important as the direct savings. We may, for instance, eliminate some of the material handling, some of the work necessary in programming the work through the shop, some of the timekeeping expense and some of the cost of establishing standards.

The most effective place to apply methods engineering is during the pre-planning stages. There are many savings which can be made during the planning stages that are not practical after tooling is built or equipment purchased. There are still many plants, however, that leave the determination of methods up to the shop people. It has been our experience that wherever this is done the methods are poorer and the speeds and feeds are lower.

We once had a good comparison between these two ways of operating when two of our plants tooled up simultaneously to make exactly the same product. In the first plant the methods were well engineered by the time study and methods department prior to releasing them to the shop. Also, the determining of speeds and feeds was the responsibility of the industrial engineers.

However, in the second plant the tooling was designed and built by the shop people and the time study department did not see the job until it was in operation.

A comparison of the standards showed that the second plant—without sound methods engineering—ended up with standards that average 50% higher than the first plant. We have, of course, since placed the responsibility for methods in this plant where it should be—in the industrial engineering department.

Material-Handling Aids

The importance of preplanning should not be overlooked in material-handling. Both the methods and production standards are inter-related with plant layout and material-handling and must be considered during the planning stages if we are to obtain maximum economy in these phases.

In terms of planning, the problem of material-handling is always in the foreground. The movement of material in a manufacturing facility often represents from 50 to 75% of the cost of processing. Movement or material-handling is at best a necessary evil to be avoided as much as possible as it adds nothing to the value of the raw material. In many instances, brute physical force is still being used—pulling, pushing, setting down, bringing in and taking out material.

If we take, for example, a company where 30 cents out of every cost dollar represents labor cost, only $\frac{1}{3}$—or 10 cents—is very apt to represent production labor. The other 20 cents is labor expended on movement. This is not an untypical ratio. Based on it, a 10% reduction in cost of movement would be equivalent to a 20% reduction in the cost of physically changing the material by direct labor operations.

Some years ago, for example, our Delta Power Tool Division made a material-handling study which resulted in the reduction of a 12-man material-handling work force to 2 men. Along with this decrease in the manpower, an additional 11,000 sq. ft. of space was made available through changes in the material-handling methods.

By combining the tasks of receiving unit loads from suppliers and handling this in-process material through our operations in the same loads, another $70,000 per year was saved. An additional $15,000 per year was saved in labor costs for receiving and shipping personnel through the same study. The total improvement through this one material-handling study amounted to $115,000 per year in a relatively small plant.

In another instance recently, at one of our plants, an analysis was made of the material-handling function in the paint department as a preliminary step toward removing a production bottleneck. Some very simple modifications in the conveyors, which handled the material, reduced the labor cost 25% while increasing production 33%. This was considered by the industrial engineering department as a preliminary material-handling step. Planning is now under way to re-layout the operation with an estimated saving of approximately 50% of the remainder of the painting cost.

It is our belief at Rockwell that during the next 10 years significant cost reduction will be made in all our plants through systematic analysis and revision of our material-handling. We consider this one of our most important projects.

'Safety Engineering'

In addition to these direct cost savings made possible through the proper use of industrial engineering, some mention should be made of the indirect savings achieved through application of this science to "safety engineering." We have gone all out in this department—first for the obvious moral purpose of protecting our employees from injury and, second, because of the less obvious cost advantages.

For every additional dollar we have spent in making our equipment and plants among the safest in existence today, we have been more than compensated financially by lower insurance rates, fewer workmen's compensation payments to make and less lost production time.

Work Measurement

Returning to work measurement, we cannot overlook its importance. Not only for cost control purposes but also for planning. Actually work measurement (or the production standard) is the basic tool of management. If we are doing the kind of job we should be doing, production standards will be used for wage incentive, cost control, standard costs, production control, methods analysis, plant layout, determination of personnel requirements, balancing of operations and cost estimating.

Because the production standard is necessary to do a good job with all of these, it is important that it be accurate. In order to establish accurate standards so that we have a sound starting point for cost control and plan-

ning, we, at Rockwell, have standardized job evaluation, wage incentives and time study as a guide to good practice. We have kept our practices as simple as possible.

We determine base rates by job evaluation. The standards we use are based on use of the figure 100% as normal with an average expected attainment of 125%. The operator is paid one for one over 100%. We have standardized on the standard hour basis. I feel that these simple policies are very essential if we are going to use the production standard for all of the phases previously mentioned.

To increase the accuracy of our work measurement or production standards, we have embarked on an extensive program to develop and institute the use of standard data. We feel it is the only practical way to maintain a balance of high coverage and accuracy in our varied multi-plant operations.

In all these efforts, we are depending on the highly specialized knowledge and skills of our staff and division industrial engineers to achieve maximum return on every dollar of investment.

We believe that management throughout the nation has only begun to scratch the surface of the vast reservoir of potential assistance which industrial engineering can offer to industry.

The Industrial Engineering Application of Communication-Information Theory

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In recent years there has been a growing realization that Industrial Engineering problems of time study, planning, scheduling, organization, etc., can profitably borrow or build techniques upon those of sister disciplines such as servo mechanisms, circuit theory, probability and statistics, game theory, information and communication theory, etc. (37). The temptation to bend these fields to the service of the Industrial Engineer is extreme, particularly as we realize that each of these disciplines has an established system of symbolic notation and a proven mathematical foundation. Extensive practical industrial engineering application of these disciplines would produce far reaching results. It would be a major step forward in eliminating the aggravating conceptual and symbolic discontinuity which usually appears as a problem moves between the mechanistic world of the other engineering fields, and the mechanistic-humanistic realm of the industrial engineer. Since rigorous techniques such as circuit analysis and servomechanism theory have already begun to influence the theory of such complicated humanistic fields as economic theory (39), it appears probable that it is now only a question of which discipline or disciplines are to become the principal analytical tools of industrial management.

Many articles have been written about the intricacies and problems of communications in industrial organizations (2), (17), (11), (23), (29), (31), (32), (33), (34), (35). The limitations of much of these works lie in the bifurcation of the words communication and industrial organization. If the broad operational definition of the word "communication" can be accepted, the words communication system and industrial organization will appear to become practically synonymous. We will then be led to believe that all production facilities are essentially communication chains that can profitably be analyzed as such by making use of modern information and communication theory.

While recognizing that the framework of the industria engineer's domain should be held for comparison against the structure of other rigorous disciplines, this article attempts to fit the industrial organization into patterns which are established by communication theory. The operational communication concept is employed. The practical results of the mathematical theory of communication are discussed without developing the detailed mathematical proof. The theory is next extended to recognize the human elements of the industrial system. Finally a number of industrial and organizational situations are examined in light of the generalized theory.

The theory which is to be developed is dependent upon the initial assumption and understanding of a very broad operational definition of the word communications. For purely mechanical systems, communication has been called the "process by which one mechanism affects another." S. S. Stevens has proposed as an operational definition that, "*Communication is the discriminatory response of an organism (object or mechanism) to a stimulus* (40)."

These definitions tell us that a communication is initiated only to affect some predetermined result and has failed if the desired specific result is not achieved. This means that the message that gets no response or the wrong response, is not a communication. By evaluating communication on the simple basis of intent and result with a yes or no (success or failure) scale, quantitative results can be obtained for a diverse span of information transmitting systems.

We are accustomed to thinking of communication in terms of human to human communication with perhaps some mechanical transmission links. In the industrial system, a high percentage of the communications are human to machine. When a production scheduler writes a work order for punch press \# 52 to produce 100 individual

stampings on a given day, he is essentially communicating with the machine. The departmental foreman and the machine operator are simply links in the chain between scheduler and machine. If the machine produces 98 parts instead of the desired 100 individual stampings, the communication received by the machine and transmitted to the raw material was 2% in error. The original message called for 100 successful machine operations. Only 98 operations got through. It is considered that of the original 100 part message, two parts were in some manner lost in transmission. Once the concept of human to machine communication is accepted, machine to machine communication appears logical and it then follows that in some portions of our industrial communication system, machines will be directing humans.

The terms information theory and communication theory are frequently associated and often implicitly implied to be synonymous. Modern information theory as developed by Claude Shannon, was the outgrowth of mechanical communication system studies. To develop quantitative theories for information handling communication channels, it was first necessary to define and measure information. This was accomplished by a statistical definition. Information is defined statistically in terms of not so much what you say, but what you could say. Information is a measure of one's freedom of choice when one selects a message. If there were only one message that could be sent, the information would be zero as there would be no choice and no point in sending the message. With information quantitatively defined, the characteristics of mechanical communication channels can be developed along with the factors such as noise which influence information flow.

From its early mechanical system applications (12), (38), (26), (44), the use of information-communication theory has grown until we now find its principles being applied to such diverse fields as Psychology (50), Psychiatry (36), Biology (18), Economics (39), and Linguistics (19), (42). It is particularly interesting to note that areas are included that in the past have presented major obstacles to even qualitative analysis.

The power of information-communication theory can be properly evaluated by considering the nature and scope of the mathematical problem that is presented and solved for the mechanical communication system. The theory is specifically designed for non-linear systems subject to random perturbations (noise) with attendant error probabilities. These systems particularly have limited transmission capacity and exhibit very sharp saturation characteristics, i.e. all information transmitted at rates above the system capacity will be in error. The theory is further designed to analyze information transmitted in continuous messages such as the speaking voice or by discrete symbols such as teletype or morse code. In the industrial organization we are normally concerned with the movement of discrete objects through a manufacturing system with a finite capacity. Both the information and the objects moving through the industrial system are exposed to varying amounts of noise and consequently are always subject to some finite error probability. Because of its mathematical structure information theory should prove the tool to resolve the industrial engineering problem of capacity, production rate, system noise, and error (quality control).

It is particularly important to note that production control, quality control, time study, etc. are statistical problems while information theory is a statistical theory. It is believed that by applying the proven mathematical basis for the mechanical components to the full humanistic-mechanistic industrial system, a vehicle will be developed for analyzing and expressing the characteristics of the system in a common engineering language. It is expected that a simplification of the industrial communication problem can be achieved for the non-expert. The average industrial engineer should be able to apply the theorems and concepts derived from communication theory to the industrial situation on both a macroscopic and microscopic basis. Macroscopically, the applications at present tend to be qualitative and conceptual. Microscopically, the quantitative time study applications have been developed (50).

It should be particularly emphasized that information theory is not a simple panacea for all communication problems whether mechanical or human. Information theory cannot do more for the industrial engineer than it has done for the electronics engineer. For mechanical communication problems, information theory has not been able to produce any information or results that experts with great vision have not been able to develop by previous more laborious methods. Information communication theory however, has offered the average engineer systematic, direct answers to problems he would formerly be unable to solve (44).

Model Theory

S. S. Stevens has said (41) "The stature of a science is commonly measured by the degree to which it makes use of mathematics. Yet mathematics is not itself a science, in the empirical sense, but a formal, logical symbolic system—a game of signs and rules. The virtue that makes mathematics more than trivial is its capacity to serve as a model for events and relations in the empirical world. Like any model used to represent something other than itself, mathematics 'fits' better in some places than in others, but at no place is there perfect correspondence between the mathematical model and the empirical variable of the material universe. Generally speaking, the fit is better to the degree that the dimensions and qualities of the things we study are measurable on well-founded scales."

Mathematical and/or conceptual models of physical systems are commonplace tools of the engineering analyst. Intricate mechanical, biological, or social organizations that cannot be satisfactorily synthesized with the conventional techniques of broad, linearizing assumptions, often can only be mastered and properly understood when a final conceptual model is constructed with a reasonable mathematical "fit". The evolution of this model normally progresses from the original qualitative system analysis to

the determination of the mathematical form of the system processes, and finally results in the selection of an initial mathematical model and set of operational hyposthesis. Since it is often too difficult to state directly whether or not the postulates correspond with reality, a testing program is necessary to check the computed performance of the model against the known responses of similar real organizations. In this manner a measure can be had of the validity of the original assumed hypothesis. Where the "fit" of the model and the actuality is intolerable, the model postulates are repeatedly adjusted and retested until the model predicts with the desired degree of accuracy the general real system performance. The words "desired degree of accuracy" obviously require individual situation interpretation, since for some systems a model giving only a good qualitative understanding of a process would be a major achievement.

While many of our operational postulates are still either unformed or poorly formed, and our means of measuring often woefully inadequate, there appears to be little question that the mathematical "fit" of communication theory to industrial organization and engineering is excellent. With the acceptance of the industrial organization as a communications system, the performance of the mechanical components of this humanistic-mechanistic system can be fully described by communication theory.

The humanistic portion of the humanistic-mechanistic system presents practical, but not theoretical problems for the application of the theory. A human machine's ultimate transfer characteristics should be theoretically expressible in terms of his purely mechanical characteristics. Suppose in a mechanistic industrial communication model, the human components are replaced by equivalent mechanical components with identical physiological characteristics. The model would then predict the best possible performance achievable from that industrial system. Since the machine replacements of the humans would possess all the human capabilities including memory, but excluding all emotions, the model would predict a performance unimpaired by the noise introduced into the real communication system by the emotional conflicts of humans. Human emotions add to the real industrial organization an additional degree of unpredictability, with a resultant predictable probability of increased system error.

In turning to the psychologist for aid in fitting the psychological characteristics of the human elements into our industrial communication model, we find that the psychologist has already discovered and applied information theory. David Grant writes, "In spite of limitations there will be extended a profitable use of information theory in the future of psychology. Stimuli are statistical in nature; so are responses; they are related—they form a communication system, single or multichanneled, with or without storage capacity. Psychology is the study of this system. Shannon's (information) theory is a most valuable tool in this study." (50). Before considering any industrial application let us examine the definitions and theorems of the mathematical theory of communications.

The Mathematical Theory of Communication:[1]

By presenting now the results and implications of the mathematical theory of communication without undertaking detailed theorem proofs, the industrial engineers' questions of "Why is it?", "What is it?", and most important, "What is in it for the industrial engineer?" can be answered.

The "why" of a theory of communication lies in the fact that the key problem of communication is one of statistical inference. In any system the message received is never a mathematically exact replica of the original transmission. In transmission the message will be subjected to random unpredictable perturbations commonly called "noise". The recipient of the message must apply statistical inference in attempting to extract the original message. Since all communication systems have some error potential, they are best described in the mathematics of statistical inference. As the "what" of communication theory is presented, the statistical nature of each element will be discussed.

The basic elements of a mechanical communication system are given in figure 1. The information source is the

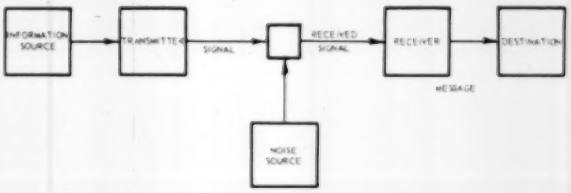

FIG. 1

device, person, persons, etc. which in order to produce a desired change in the state of the destination, selects a desired message from a set of possible messages. The transmitter changes the message into a signal form which can be conveniently transmitted by the channel. We say that the transmitter encodes the message for transmission. The channel is the machine over which the signals representing the messages are transmitted to the receiver. The receiver decodes the signals into the message normally in a form meaningful to the destination. Noise is said to be any additions to—or distortions of—the original message. It is obvious that noise may take many forms. However, it is essentially any deviation from the original source intent and consequently noise might well be called *error*.

The block diagram of the mechanical communication system can be readily illustrated by a great number of physical situations. Since Shannon's work was sponsored by the Bell System, the names given the elements of the block diagram are fully descriptive of the situation of telephonic communication between two individuals. In this case at least, the concept of noise is easily related to one's personal experience. Again note that the communica-

[1] As developed largely by Claude Shannon for mechanical communication systems and with concepts from Shannon and Weaver (38), Sanford Goldman (12), Brockway McMillan (50), and Liefer and Schriber (26).

tion engineer considers any change from the original as noise. It is the problem of grappling quantitatively with this random statistical phenomena of noise or error that has largely resulted in modern communication theory. With the recognition of noise the extent of the system elements task is further clarified. The receiver or decoding device must not only decode the original noisy signal, but it must also infer what the original signal really was.

Along with the noise that nature and man introduce into his communication channel, the engineer must concern himself with the additional all important statistical problem of bulk or volume of channel message traffic. The message bulk will be intimately related to the encoding process. One can easily verify experimentally that a long sample of English text can be readily restored to its original form even if half its letters or all of its vowels are deleted. Since in English all letters do not occur with equal probability, i.e. the letter u always follows the letter q, and because of the unique meaning inherent in a long passage, there exist strong statistical connections extending over stretches of message. When a channel transmits English messages, its true information content is reduced because part of the message is devoted to telling us something we already know—the probability structure of the English language. All that is really needed is enough key data to allow a unique restoration of the original message. All other material would be redundant and a waste of channel capacity.

The latter part of the above sentence is not entirely true, however, for redundancy and noise interact. In a noisy channel where some of the message will probably be received in error, redundancy can be effectively used to reduce the final message error to any desired fraction. A common example of the manner in which the final decoder uses redundancy can be seen in the ease with which we normally perceive the correct message even in badly misspelled telegrams.

Shannon has posed and answered four questions about the general communication problem (38):

1. How to measure amount of information and rate of information production in a manner which will take into account the probability structure of the message?
2. How to measure communication channel "capacity"? How many information units per second can be sent through a channel with a given signal power and a specified noise?
3. What are the characteristics of an efficient encoding process? With maximum encoding efficiency, at what rate can a channel convey information?
4. What are the general characteristics of noise and their effect on final message accuracy? How are the undesirable effects of noise minimized?

Information:

In the following section while we are concerned only with the mechanical aspects of communication, information is not to be confused with meaning. One's initial contact with information in communication theory usually seems strange, for here information relates not to what you say, but to what you could say. Information is a measure of one's freedom of choice when one selects a message. If there were only one message that could be sent, the information would be zero as there would be no choice and no point in sending the message.

It has been found that information may be conveniently expressed in binary code or in other words, measured in terms of $\log_2$. For example, if one had 16 alternate messages from which he is equally free to choose, then $16 = 2^4$ and $\log_2 16 = 4$. This means that the situation and its particular message could be characterized by 4 "bits" of information from a binary coding system.

If a situation is highly organized, it is not characterized by a large degree of *randomness or choice*—that is to say, that the information is low. *Maximum* choice or *information* for a given set of symbols will occur when the probabilities of occurrence of each symbol are equal.

Relative information for a given situation is defined as the ratio of the actual information (freedom of choice) to the *maximum* possible *information* for the same set of symbols. *Redundancy* is defined

Redundancy = 1 minus *relative information* Eq. (1)

Redundancy then is the fraction of the message that is determined not by the choice of the sender, but rather by the statistical rules governing the use of the symbols in question. As was pointed out, this fraction of the message could be omitted in a noiseless situation and the message would still retain full information. English has been proven to be approximately 50% redundant.

Information "H" is mathematically expressed for the case of interdependent symbols whose probabilities of choice are $P_1, P_2 \cdots P_n$ by the equation

$$H = -\sum_i P_i \log_2 P_i \qquad \text{Eq. (2)}^2$$

The minus sign only appears since P_i is usually less than one and H is taken as a positive quantity. If the probability of any symbol is unity, (symbol is certain to appear each time) $\log 1 = 0$ and the information is zero since only one symbol will always be transmitted. The units of H are bits per symbol.

Channel Capacity is defined in terms of the amount of information correctly transmitted per unit of time. Bits per second is the common unit. For example, a teletype channel could have a source that may freely choose from among 2^s symbols. Each symbol chosen then represents $\log_2 2^s = S$ bits of information. If the channel is mechanically capable of transmitting n symbols per second, then the capacity C of the channel would by definition be ns bits per second.

At this time we have defined information H in terms of

[2] This form is similar to the defining equation for *entropy* in statistical mechanics. The term entropy has been adopted in classical information theory for the measure of uncertainty or information. Thus information theory is linked to the thermodynamics of Boltzman and Gibbs with the result that the mathematical methods of statistical mechanics form a guide for information theory development.

bits per symbol. Information can also be rated in bits per second, in which case the symbol H' will be used. Without stating how we would determine the capacity, C, of a real channel, C has been defined in bits per second. With this rather elementary background the fundamental theorem of communication can be stated in all of its simplicity.

Fundamental Theorem of Communication:

"By proper coding procedures it is always possible to transmit symbols over a channel of capacity C, when fed from an information source of H bits per symbol at an average rate of nearly C/H symbols per second with zero error. However, no matter how clever the coding, the errorless transmission can not exceed C/H."

The fundamental theorem can be stated another way. If the information source generates at a rate of H' bits per second and feeds a channel of capacity C then errorless transmission can be approached if $C > H'$.

Information has been defined in terms of the freedom of choice in selecting a message. The greater the freedom, the greater the information, and the greater the uncertainty that the next message to be received will be some particular one. *Noise* causes the received signal to exhibit greater uncertainty or more apparent information than the transmitted signal. Noise therefore, is undesirable uncertainty or information which tends to confuse the decoder and cause errors. The powerful fundamental theorem states rather simply, however, that no matter how much noise is present, a coding method will exist that shall allow errorless transmission at a rate H' which shall approach C the channel capacity. The statement of errorless transmission in the face of error producing noise is provocative. The only possible joker in the erstwhile simple statement might lie in the still unexplained derivation of C. (It so happens that C will be dependent upon the amount of noise present in the channel as will be subsequently shown.)

By illustrating the fundamental theorem with an example, it is possible to tie together the implications of noise, channel capacity, rate of information transmission, redundancy, transmission accuracy, the coding problem and coding time. Consider the following elementary situation: A channel is capable of mechanically transmitting 100 numbers per second. However, the noise in the channel is great enough to insure that one (and only one) number out of each 100 transmitted is received in error. If this is an intolerable accuracy, we immediately look for some means of improving the transmission accuracy through this noisy channel—assuming we have no control over the channel and its error producing rate. The first and most obvious approach would be to catch the errors by introducing message redundancy into the communication. If each number transmitted were repeated before the next number were transmitted, any number transmitted in error would immediately show us as it would not match its preceding (or following mate). Thus by introducing 50% redundancy into one's message, we could immediately spot any error when the second number of the pair was received. This simple error detecting redundancy has the advantage of speed. It has the disadvantage of a 50% reduction in original number transmitting capacity, plus the inability to tell which of the unmatched pair is correct.

By transmitting each number three times, 66.6% redundant, the transmission can be made 100% accurate. However the useful capacity of the system would now be only 33 numbers per second. The fundamental theorem though would lead us to expect much greater capacities for the system.

Let us try a slightly more sophisticated coding scheme with controlled redundancy. Suppose the numbers were transmitted in the sequence indicated in the following array:

a_{11}	a_{12}	a_{13}	T_{R_1}	$T_{R_1} = a_{11} + a_{12} + a_{13}$
a_{21}	a_{22}	a_{23}	T_{R_2}	
a_{31}	a_{32}	a_{33}	T_{R_3}	
T_{C_1}	T_{C_2}	T_{C_3}		$T_{C_1} = a_{11} + a_{21} + a_{31}$

Where the a's are the original transmission numbers and the T's are the controlled redundancy with T_R's equalling the sums of the rows and T_C's equalling the sums of the individual columns. For every 15 numbers transmitted, 6 are redundant for a redundancy of 40%. The code is self checking. An error in any one single number in the array can be found and corrected by the time T_{C_3} is received. Now if a 9 x 9 array were used instead of a 3 x 3, 81 useful numbers would be transmitted along with 18 redundant check figures. In this case the redundancy is only 18/99 = 18%.

The useful error-free transmission capacity has been increased to 81.0 numbers per seconds, but it is now necessary to wait for the transmission of up to 99 symbols in order to read the complete message i.e. find and correct the error that must be present in every 100 numbers transmitted.

The heuristic proof embodied in our example bears out the fundamental theorem. By clever encoding we are able to use controlled redundancy to cause the error free transmission rate of the system to approach the capacity of the channel. However, this increase in rate is not obtained without sacrifice, for the waiting time for message decoding (correction) increases rapidly as the transmission rate approaches its theoretical error-free maximum.

The ultimate error free capacity of a noisy channel has been developed by Shannon for the transmission of both discrete and continuous symbols.

Capacity, C, of a discrete channel

$$C = \text{Max}\,[H'(y) - H'_z(y)] \qquad \text{Eq. (3)}$$

$H'(y)$ —Total information including noise in received signal

$H'_z(y)$—Information (uncertainty) contributed to received signal by noise.

The maximum is with respect to all possible information sources used as input to the channel. For a noiseless channel, $H'_z(z) = 0$. Note again that the Fundamental Theorem says that for $H' > C$, the minimum error regardless of coding cannot be less than $H' - C$. Equation

(3) lends itself to an experimental determination of C. Over an extended period of time, a record can be kept of the messages sent and the results achieved (messages received). At a later time a symbol by symbol comparison can be made and the probability of each received signal re-evaluated and averaged. Where the received symbol coincides with the message symbol, the probability is one and information is zero. $H_x(y)$, the uncertainty of the received signals will be left. Shannon and Weaver offer further examples to illustrate the idea of capacity of a discrete noisy channel (38).

The industrial engineer will undoubtedly apply the discrete channel theory to his production line problems, where he usually deals with discrete objects. However, there will be many occasions where the continuous messages such as the speaking voice will be used. The continuous signal, maximum capacity theorem is especially important for the light it throws on the relations between capacity, signal strength, and noise magnitude.

Continuous Signal Maximum Capacity Theorem:

$$C = W \log_2 \frac{P + N}{N} \text{ bits/sec.} \qquad \text{Eq. (4)}$$

C—Maximum capacity of channel of
W—Frequency band width
P—Average signal power
N—Average noise power

The theorem indicates that with zero noise, the channel capacity becomes infinite. With efficient coding, information could then be transmitted at an infinite rate. Unfortunately, there are no truly quiet places on our earth. In every physically realizable system some noise will exist and C will be finite. The formula further indicates the well-known threshold concept for as N approaches and exceeds P in magnitude, $\frac{P + N}{N} \to 1$ and $\text{Log}_2 \frac{P + N}{N} \to 0$ or zero useful capacity.

At this point we have completed our simplified presentation of the mathematics of communication as developed for mechanical systems. Without further expansion these mathematics could be used to describe and predict the ultimate performance of a humanistic-mechanistic industrial organization with the people replaced with perfect "man machines". To account for the somewhat less ideal performance of the actual system, it is not necessary to modify the mathematics, but only to recognize the additional error probabilities introduced by the human elements. This can be best accomplished by rapidly previewing the all important concept of channel capacity.

Channel Capacity Meanings:

A channel for transmitting code messages is a complete transmission system from an input location to an output location. The properties of the channel include the properties of the equipment used in the channel as well as the properties of the codes or languages used. Channel capacity can usually be specified at least three ways—in terms of code capacity, language capacity, and semantic capacity. The code capacity of a channel is determined by the fixed constraints which may be part of the code channel (for example the dot-dash-space of electrical telegraphy) plus all the fixed constraints which may be present in the letter, word, and sentence codes of the language employed in the channel. The language capacity of a channel is obtained by superimposing the probability constraints of the language upon the fixed constraints of the code channel.

It can be proven that the language capacity of a channel will be less than its code capacity unless the probability of occurrence of a symbol is properly matched to the time duration of its code transmission. For example, the letter e being the most frequently employed in English would require the shortest code representation.

Language capacity as used herein is defined in terms of symbol by symbol (i.e. letter) transmission. In the mathematics of the mechanical transmission system, no attention is given to the meaning of the language symbols since meaning has no influence in the design of the system.

Semantic information and consequently semantic capacity can be defined by the basic information definition:

$$\text{Information received} = \log \left[\frac{\text{Probability at the receiver of the event after the message is received}}{\text{Probability at the receiver of the event before the message is received}} \right]$$

The numerator accounts for the noise in the system for in the noiseless case:

$$\text{Information received} = -\log \left[\text{Probability at the receiver of the event before the message is received} \right]$$

Goldman (12) has discussed language and semantic capacity in some detail. Weaver (38) points out that the introduction of the semantic problem causes a modification of the rather simple diagram of figure 1 to recognize that a "semantic receiver" is interspersed between the mechanical receiver and the destination (Fig. 2). This semantic receiver performs a second decoding upon the message for it must match the statistical semantic characteristics of the message to statistical semantic capacities

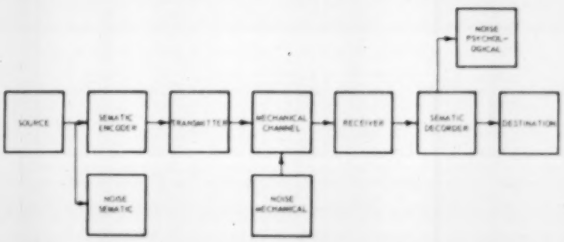

Fig. 2. Complete Communication System Block Diagram

of the receivers. A semantic encoder exists between the information source and the transmitter to encode the intended meaning of the sender into symbols that the receiver can satisfactorily decode. In addition, a box must be introduced at the source entitled semantic noise to account for perturbations or distortions of the meaning not intended by the source, but which effect the destination.

The semantic problem of the industrial situation is enormous. Undoubtedly a substantial portion of the difference between ideal and actual industrial performance can be traced to semantics. Adequate semantic channel capacity requires not only a common language, but a good vocabulary match, and an extensive sharing of cultures and experience. Here the meaning of the word semantics must be expanded to include not only the meaning of words, but the meaning of situations, and experience. The term semantics is used here to imply meaning, not just the dictionary meaning of the words transmitted, but meaning in terms of the original *intent* of the sender.

The dependence of channel capacity upon this expanded view of semantics is illustrated by the oft paraphrased story of a college professor who, lost in the mountains, asked a hillbilly for directions (13). After the professor indicated he didn't know where Knudsen's bridge, Gin Creek, or Ma Perkin's hog wallow were, the mountaineer gave up in disgust, saying, "You can't tell nuthin' to nobody who don't know nuthin' to begin with".

He was correct, for in terms of the mountaineer's message, the professor's semantic channel capacity was zero. They both spoke and understood the same language, but lacked the common object identification experiences which would have allowed them to communicate. Although the recognition of semantic mismatch between source and channel is frequently difficult, once the problem is recognized, it is relatively simple to evaluate in terms of the mathematics of communication theory.

The introduction of the effects of the emotional characteristics of the human components represent the last adjustment that must be made to the mechanical communication system to faithfully simulate the industrial organization. Human emotional factors normally manifest themselves in the form of extraneous noise introduced between the semantic decoder and the destination (Fig. 2). Because of its psychological origin, we have chosen to call this noise "psychological noise". "Psychological noise" is intimately associated with what other writers have called the "effectiveness" problem (50).

Psychological noise can be activated either by the message itself which may disturb the receiver or by events outside the work place. Emotional factors can also cause additional semantic noise. A subordinate will frequently attempt to encode a message so as to both convey information and still please his superior —a situation usually not conducive to accurate communication. The effects of psychological noise are the same as those of mechanical noise. The useful channel capacity will decrease as the noise increases. While the system performance with varying amounts of psychological noise is readily understandable qualitatively, much experimental work must yet be performed before quantitative results are available. The extreme change in performance that can be observed in a normally efficient worker under severe emotional stress is not surprising when considering the channel capacity expression:

$$C = W \log \frac{P + N}{N} \qquad \text{Eq. (5)}$$

where P is the power of the message signal and N is the magnitude of the noise. With the introduction of semantic and psychological noise, the application of the mathematical theory of communication and its concepts to the industrial communication chain can now be studied in some detail.

Industrial Communication Criteria:

Stated in its simplest form it is the responsibility of industrial management to develop the most efficient, rapid, and accurate system possible for the transmission of the customer's request (order) from the sales department through the plant to the shipping department. In other words the industrial organization is simply a complicated communication system which enables the customer to communicate with the shipping clerk.

Information theory can be applied industrially on both a microscopic and macroscopic basis. Microscopically, communication theory data and techniques are available to give numerical answers to a potentially wide variety of problems involving the individual human machine. Macroscopically, communication theory enables the engineer to assume the proper perspective in evaluating the overall communication system. He is able to translate the requirements of good humanistic-mechanistic communications into engineering terms and properly evaluate qualitatively if not quantitatively, the relative effects of each factor. Knowing all the requirements for accurate communication, he can in complicated systems experimentally determine the system parameters. At the simplest evaluation level he can avoid those situations unfortunately so common in industry, where accurate communication is literally impossible.

On either a microscopic or macroscopic level, the method of system design is deceptively simple. First the maximum rate, H', at which information must be transmitted is computed, usually in units of bits per second. Then the maximum rate, channel capacity, at which the proposed system can transmit information is determined using $C = W \log_2 \frac{P + N}{N}$ for continuous waves or $C = H'(y) - H_x(z)$ for discrete symbols. If the capacity is greater than the required transmission rate, then the designer is in luck. He has only to decide on the amount of controlled message redundancy he will allow for maximum clarity. If $H' < C$, then the designer is in trouble. He has the choice of obtaining a better channel by decreasing noise, increasing signal, finding better facilities, reducing some of the message redundancy, or of giving up entirely.

Microscopic Analysis:

On a microscopic level the analysis of the information capacity of the mechanical machine has been so completely formalized that we shall consider only the problem of the human machine. Even in the most menial tasks, the human machine is employed only in situations where the operations require some decision making. In ordinary time and motion analysis, the industrial engineer wishes to minimize the time required for a combination of physical movement time and decision time. Decision time is the lag between stimulus and response. Time and motion analysis may be considered a study in human information generation and transmission. Man's information transmission capacity is limited by the fixed constraints of the human motor system and by the kind of coding required for individual tasks. As in all information handling systems, transmission efficiency is a function of coding. Maximum human information handling capacity requires the selection of an optimum stimulus code, the selection of an optimum response code, and finally the matching of the two coding schemes. The capacities of various human information handling channels should be of fundamental interest in time and motion analysis. The average typist can type 60 words per minute without error. With each word averaging five letters, this comes to 300 letters per minute. If the typist were producing nonsense letters, the information contained in each letter would be $\log_2 26 = 4.7$ bits letter. When the constraints of the English language are applied extending to groups of eight letters with English occurrence frequencies and interletter constraints, the information per letter drops to 2.35 bits. Thus the average typist produces $\frac{2.35 \times 300}{60} = 11.75$ bits per second while an expert at 120 words per minute can convey 23.5 bits of information per second. A superior telegrapher can also produce 60 words per minute. The stenotype operator using a more efficient coding system with less redundancy can readily transmit 120 words per minute or 23.5 bits per second. Court reporters can double this and handle 47 bits per second. These preceding figures were all based upon random words. In English text where there are substantial interword constraints, the information per letter is approximately one bit per letter or 5 bits per word.

The linguist describes speech with a little more than 30 elements called phonemes. If each element were independent and equally probable, they would each produce five bits of information. A speaker producing random phonemes at the rate of 10 phonemes per second would generate 50 bits of information per second. With interword constraints this would amount to about 25 bits per second.

The above human channel capacities appear very low when compared to those of say an ordinary noisy radio channel with a bandwidth of 5000 cycles per second, a signal to noise power ratio of 1000, and a resultant capacity of $C = 5000 \times \log_2 1001 = 50{,}000$ bits per second. However, even in the seemingly relatively simple human information channel represented by the typist, information is visually received, decoded in the typist's mind, and then recoded into impulses to be transmitted by the typist's fingers to the paper. Information handling capacity in the human machine will vary tremendously depending upon the coding match and the human channels utilized.

Where maximum response rates are desired, the conduction delay of the nerve channel selected can be important. The impulse conduction velocity of nerve fibers ranges from 100 meters per second down to less than two meters per second (41). These conduction speeds make the average reaction time of 200 milliseconds for simple motor tasks seem quite reasonable. Thus for motor tasks restricted to a yes-no response, our human channel can produce only about 5 bits per second. On the other hand, a 500 line television screen would contain 250,000 dots. If the dots have equal probability of being black or white, and if the eye can distinguish all and each dot at a rate of say 3 times per second, then the visual information received could be 1,250,000 bits per second. The visual tract is by far the highest capacity human channel. The average reader can read 250 words of text per minute or 21 bits per second. A trained reader can reach 600 to 900 words per minute or a ceiling of 75 bits per second.

The quantitative application of information theory to time and motion control can be derived from Paul Fitts' work on Response Coding In Motor Tasks (50). Fitts has used information theory to analyze two basic motor tasks. The first involved selection of direction and amplitude of motion. It was an experiment to determine decision and movement times after receipt of a coded stimulus. The second experiment was a repetitive motor task to develop the relations between rate, amplitude, and accuracy in repetitive movement operations.

In the first task the workman was required to move his finger from an initial point to one of a set of targets whenever a light appeared behind the designated target. The initial point and the targets were placed upon a straight line as in the following sketch (Fig. 3) with targets of equal size. Reaction time (decision time) and movement time were measured. The first test runs were disappointing.

Fig. 3. Motor Response Task

As was expected, the movement time increased with target position while the reaction time increased with the number of choices. However, it was not the same for each target within a given choice set. In order to maximize the information transfer for a given number of targets, it is necessary to have the same reaction and movement times for each target in the set regardless of position. This was finally achieved by having the width of the targets increase in a logarithmic progression of the distance from the starting point of the movement. In a 16 choice set, the width of the first target was $\frac{1}{16}$ the size of the farthest target. With the new logarithmic configuration, it was

found that decision and movement times both increased linearly when plotted against the log of the number of alternative targets presented. This is in keeping with our theory as the greater the freedom of choice presented to the worker, the more information each movement generates. Yet since the accurate information conducting capacity of the worker is a finite number, the more information each motion generates, the slower the worker must react in order to remain accurate.

To determine the response factors in the performance of repetitive motor tasks, Fitts gave his workmen simple repetitive movement tasks which the workmen understood perfectly and which they were expected to perform as quickly and accurately as possible. The problem to be assayed was man's information generating capacity for repetitive tasks requiring different combinations of accuracy and amplitude of movement.

The experiment involved a reciprocal tapping movement in which a stylus was to alternately be tapped against two rectangular plates. The heights of the plates were held constant at 6" but the width *Ws*, was varied in geometrically increasing steps ($^1/_4$, $^1/_2$, 1, and 2"). The center to center plate separation distance, *A*, was also varied in four steps (2, 4, 8, 16 inches) to give 16 combinations.

The workmen were asked to hit each plate in turn as rapidly as possible with minimum error. This would in essence reveal his maximum capacity for repetitive motor tasks since maximum information would be generated with negligible error. Plotting the log of the movement in operations per second against the log of the tolerance (*Ws*), the experimental results were found to be four uniformly spaced lines—one for each amplitude of *A*.

These results would indicate a logarithmic relation between response time, width *Ws* and separation *A*. If the target width (*Ws*) is divided by twice the distance traveled, *A*, a ratio is derived which can be considered the probability of hitting the target by chance. This is based on the assumption that the movement might terminate at any point between its initial point and a point equidistant from the target on the opposite side. If a negative logarithm to the base two is taken, a unit is developed which resembles the information unit. Fitts points out that since the result is not an exact (although close) measure of information, he prefers to call it the Binary Index of Task Difficulty. By dividing the task difficulty (which corresponds to bits per symbol) by the average time required to complete one response, we have a rate index to be called the Binary Index of Task Performance (corresponding to bits second). The results of average data taken from 16 subjects is tabulated in table I.

The experimental data of table one would be remarkable in light of anything but information theory. Although the movement frequency varied widely from nearly 3 C.P.S. to 0.7 C.P.S., the information generated by the particular motor task as typified by the Index of Performance remained relatively constant over an extreme range of conditions. Fitts' work will have extensive applications in the quantitative extension of time and motion data. It is to be noted that with the exception that the relationships

TABLE I

Summary of Data from Sixteen Subjects on the Tapping Task

W_s (inches)	A (inches)	$-\log_2 \frac{W_s}{2A}$	Mean Time Per Response (sec.)	Binary Index of Task Performance
.25	2	4	.392	10.20
.25	4	5	.484	10.33
.25	8	6	.580	10.34
.25	16	7	.731	9.56
.50	2	3	.281	10.68
.50	4	4	.372	10.75
.50	8	5	.469	10.66
.50	16	6	.595	10.08
1.00	2	2	.212	9.43
1.00	4	3	.260	11.54
1.00	8	4	.357	11.20
1.00	16	5	.481	10.40
2.00	2	1	.180	5.56
2.00	4	2	.203	9.85
2.00	8	3	.279	10.75
2.00	16	4	.388	10.31

are logarithmic instead of linear, information theory allows all of the techniques of ordinary model theory to be used to predict extended range performance from original model test data. Fitts' work emphasizes the coding problem. If every movement at a work station has equal probability, then for maximum production, the total response time (sum of decision and movement times) for each movement must be made equal. In his first experiment Fitts showed that to equalize response times the small objects must be closest to the operator. If parts were to be taken from bins, then the bin sizes should increase logarithmically with distance.

Communication theory further tells us that at any given time each human machine has a fixed maximum information transmitting capacity *C*. The theory states that no matter how efficient the work place, the workman cannot produce accurate work (information) at a rate even slightly in excess of *C*. Human repetitive production rates are seen to have maximums lying between 5 and 20 bits per second. Fitts has shown the possibility of correlating tasks with widely varying parameters. With further experimental data and proper adjustment for fatigue etc., his Binary Index of Task Performance could well become the key to true time and motion synthesis. At a different level an equally intriguing application would be the measurement of human information transmitting capacity for personnel rating and job placement.

Macroscopic Analysis:

It is the author's opinion that the basic theorems of information theory will prove to be the I. E. tools for reducing the seemingly overwhelming complex intricacies of modern industrial information flow to a reasonably simple mechanistic model, subject to qualitative analysis and the application of round number judgement values.

Recognition that the industrial man is a decision making machine capable of transmitting information accurately

at a fixed maximum rate, makes the requirements for good industrial organization seem almost ridiculously simple. If a decision is to be made from a large number of real or pseudo real choices, then that decision represents a large amount of information. Since the individual can only transmit information accurately at a fixed maximum rate, the greater the information content of each decision (or movement) the slower the rate at which decisions can be made. This points out immediately the sweeping necessity for reducing the number of choices available per decision.

We see now that production varies inversely with the logarithm of the number of choices. In the engineering department this concept highlights the need for part, method, and design procedure standardization. On the assembly line the motion production rate of the workman will increase as the number of different physical movements for a task is decreased. To the personnel director, the concept further emphasizes the need for experience and training. In the average industrial situation, the number of true choices available to the individual for each decision are extremely limited. The experienced man has learned the options available to him. The production rate of the inexperienced man, however, is much lower as he must make his decisions from a larger array of choices. This array is larger because it includes many pseudo choices that can be ignored only with experience.

The industrial communication system is particularly well adapted to the application of automatic error reducing techniques, i.e. feedback controls. At all levels of the communication-production process it is normally possible to establish feedback channels which serve to compare the results of a communication with its original intent. Many of these feedback loops already exist in the factory under the headings of inspection, quality control, cost control, sales reports, production reports, and finally profit and loss statements. With accurate feedback, communication performance or error is usually obvious.[3] The failure of mechanical elements are readily traceable. Inadequate performance of the human elements may require a point by point application of the tenets of communication theory. In fact the industrial engineers' scientific method of problem solving can be profitably rewritten from a communication viewpoint (43).

Efficient, accurate information flow is a product of two basic factors—channel capacity and code matching. Since all information above the channel capacity will be transmitted in error, the system capacity must be examined in detail element by element. For evaluation of the human components, particularly in higher order decision making positions, the importance of experience, training and long time group association cannot be overemphasized. Intelligence can learn by experience, but in the industrial situation, intelligence cannot replace experience. This is particularly true since human decision is based upon simulated or actual experiences. Within an inexperienced group or a group containing new and inexperienced members, communications will be very slow and redundancy will of a necessity be high to preserve accuracy. Experiments in military group information transfer have shown that the conventional so-called learning curve can be attributed to a combination of increased channel capacity and more efficient coding. As the individual learns his task, channel capacity increases with decreased semantic and psychological noise. Message redundancy can be materially reduced when the encoder is certain that the decoder has recognized the limited number and range of commands applicable to the situation. For example, in a newly formed radar warning group, an interpersonal message might be, "Corporal Watkins, 'Note and record the object showing in sector 32 of the radar screen and interrogate it for the code of the day'." After months of association the same command may become simply, "Sector 32!" The encoder by then would know that Corporal Watkins was responsible for sectors 29, 30, 31, and 32. The command, "Sector 32" would automatically limit Watkins to a scan of sector 32 with an interrogation of any objects sighted. Decision making on Watkins' part had also been simplified. He had only to identify and survey one of four sectors upon receipt of a suitable command. The code necessary for complete transfer of information in this simple instance need only be four numbers.

The effects of psychological and semantic noise upon organizational communication channel capacity can too often be described only as catastrophic. Although a number of articles have been written describing the advantage and problems of two-way communication (32), (35), it is seldom recognized that in most instances accurate communication through the upward or feedback path is literally impossible. In order for an organization to operate at all, some downward communication capacity must be formally established and maintained. Upward feedback channels are not used as frequently and consequently contain considerable semantic noise. This becomes particularly evident in the case of new or inexperienced management which has not shared experiences with its subordinates. In a like manner, communication from subordinates upward is subjected to much psychological noise. Many cases have been observed where management's displeasure over unfavorable reports has gradually forced subordinates to relate only that which they thought management wanted to hear. In these instances, information being passed upward has become 50% to 75% inaccurate or incomplete. Accurate management feedback can exist only in formalized channels where top management has earned the confidence of its subordinates.

The total responsibility for successful production must rest with the original message encoder. He must devise a code which will match the code characteristics of the channel in order to produce a maximum transfer of useful information. He must produce information at a rate and with sufficient redundancy to minimize error. Where feedback channels have been established, he must recognize the changing nature of the channel and continuously

[3] "Accurate Feedback" must be emphasized since the feedback channel is in itself subject to noise and error.

rearrange his coding to further maximize the information transfer. As in our radar screen example, the coding redundancy can be reduced as increased capacity is developed. Each succeeding message recorder in a long communication channel shares the responsibility from his station onward.

The encoder must further recognize when insufficient channel capacity exists and why it exists. Insufficient capacity in general can be the results of the mechanical characteristics of the systems, i.e. human response times or of an inadequate signal to noise ratio. While it is usually difficult to improve the human mechanical system, human channel capacity can frequently be enlarged by increasing signal strength or by reducing attendant noise.

To reduce noise, it is necessary, of course, to recognize its presence and type, whether mechanical, semantic, or psychological. An example that comes to mind is the case of a California school system where a conscientious superintendent found that he and his staff were unable to establish any degree of satisfactory communication with intelligent and interested parents. He ultimately recognized a semantic problem. For while he was speaking in the native tongue of the parents, he was attempting to relate pupil reactions which dated back to the parents' forgotten childhood, or teacher problems which the parents had never experienced. To reduce the semantic noise and establish a satisfactory channel, the superintendent persuaded groups of the parents to come to the schools for two weeks. During this period, they were given many of the typical lessons presented to their youngsters, and were exposed to the problems of the teachers at the same time.

A further example of management communication capacity was that of a large western manufacturing concern where the chief industrial engineer was unable to satisfy the sales manager on the order release procedure. The sales manager had handled order releases when the company was smaller and could not be told that existing production levels precluded the use of their older methods. The problem was solved when the sales manager had shared the industrial engineer's experience by the taking over of the responsibility of order release for a few months.

Conclusion:

The particular strength of the communication theory lies in its ability to describe in the precise language of mathematics the statistical performance of all components, human or mechanical, of the industrial engineers' realm.

Although their rigorous mathematical proofs are long and tedious, the theorems of communication theory are simple, easily understood, readily translated between words and symbols, and applicable to practical problems with a modicum of effort. Experimental data correlates quite well with theory. The mathematical techniques lend themselves easily to the use of extended model theory.

Human performance becomes measurable, predictable, and describable in a common language, a language that the I. E. will find is already in use by psychologists, linguists, psychiatrists, and other engineers.

The I. E. adoption of communication theory will of a necessity be slow. He will have to learn to think in terms of logarithmic scales. Experience will have to be gained in applying the mathematics to detailed problems and more case histories of industrial organization examined in light of the general theory. However, Fitts' work has already added another dimension to Time and Motion study and pointed the way to Time and Motion synthesis.

While it was the author's early conviction that information-communication theory would prove a useful mathematical tool for the I. E., the advances of the past few years have led to the conclusion that more than this, the theory shall become the Mathematics of Industrial Engineering.

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The Problem of Pride

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The problem confronting the Industrial Engineer every hour of his working day is that of production. The problem may be with any one or all of the four M's of engineering; Men, Materials, Methods or Machines. Occasionally the solution may be relatively simple—a new machine with automatic devices; a new, better quality material; revision of existing methods through work simplification practices and other methods familiar to each of us. It is the problem of increasing production by dealing with Man alone that cannot always be solved by simply removing the old and replacing with the new.

Various devices have been suggested through the years to furnish an added incentive to Man to increase his production. Many concerns have equitable wage incentive plans, suggestion programs for methods improvements, and other means of recognition which are intended to further Man's interest in increasing production and, thereby, his standard of living.

However, even with the various plans and other devices supplied by management, production will still suffer if there is a lack of Pride. Many of today's problems of production delays, poor quality, and high manufacturing costs, can be laid to a lack of this little five letter word—*Pride*.

With today's trend toward specialization and automa-

tion we have ventured away from the practice of years ago when a man was an artisan in his job. A craftsman who designed his product and carried it solely through to its creation. While the practice of specialization, one job only being performed, assembly line methods, and other like changes in manufacturing methods have increased production and thereby lowered costs, we have lost sight of this most important aspect of Man's life—Pride in his work. The man performing the same repetitive operation over and over again hour after hour may become so skilled that he can perform the operation with his eyes closed, but in so doing he may have lost pride in doing a job well, and in seeing the value of his efforts to the overall company product. We in Industrial Engineering must meet the problem of increasing production without allowing the Man to become a Robot.

The employee of greatest value to his company is not necessarily the one who gets the job done fastest, but the one who can combine his job skill and knowledge into his work with a feeling of having done his job well.

Many companies have recognized this problem and have come up with various methods for making the employee feel he has a share in his companies product. The statement: "This box printed by John Jones and crew" which appears on some containers today is one way of giving recognition to the employee and establishing the feeling that he has contributed to the finished product. Another company has placed on their machines this statement: "This machine represents our best efforts". With signatures of the employees responsible for its assembly etched onto the name plate. These are but two attempts of companies to establish a feeling of pride in the work of their employees. They are not necessarily a solution to the problem nor can similar means be used by all companies to solve this problem.

We in Industrial Engineering are in daily contact with the employee. As representatives of management we are in a prime position with other supervisory personnel to assist the employee to regain the feeling of pride in his work.

No simple formula can be given to remedy this problem—it's a selling job and one which deals with individual personalities. The solution lies in working with the employees, recognizing their problems, the simple "pat on the back", by giving credit where credit is due, and most important, by having pride in one's own work. By setting a proper example for the other fellow the job can be accomplished. An employee with a feeling of pride in his work will automatically turn out quality work at lower cost.

The Assignment of Operators to Service Automatic Machines

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Waiting line theory addresses itself to that broad class of problems where service of some kind is provided in the face of non-regular calls for such service. Waiting time occurs when a call for service originates and all available servicing channels are already busy. Prediction of waiting time depends, then, on a complex probability, i.e., the probability of a call for service and, given this call, the probability that a servicing channel is clear. The classical problem in waiting-line theory is that of trunk lines servicing a telephone exchange. (1) A few industrial applications have been made, but two major difficulties have been encountered.

The first is the difficulty of computation of waiting times. This difficulty may largely be overcome by high speed computers, however. The second, and more important, has to do with ascertaining the validity in industrial applications of the basic assumptions it is necessary to make regarding the probability of calls for service and the distribution of servicing times. It is in an attempt to get at this latter problem that this paper has been written. An industrial application of this theory is presented with the hope that trials will be made in industry and data fed back so that the assumptions may be verified or modified accordingly. It is hoped that the nature and limitations of the assumptions made in this paper will be accounted for in each specific situation where a trial is made. The derivation of the basic waiting line model is not included in this paper but may be found in the references. Here are presented only methods of attack, computational formulas, and tables, that is, all that is necessary for actual applications.[1]

The Machine Assignment Problem

The application treated is that of determining machine assignments where an operator may service more than one machine and synchronization of servicing times is not feasible; that is, where operator attention per machine averages one half or less of his available time and where calls for service are subject to some variation. In such cases, waiting time will occur when machines call for service time while the operator is attending to a machine which has given an earlier call for service.

Even in situations where the running time of the machine between service calls is reasonably stable, any

[1] The author is indebted to Richard L. Van Horn, Jr., of M.I.T. for his assistance in research and computation.

small variation in servicing time or running time which occurs may occasion some waiting time. Since waiting time can cause additional waiting time (if a machine calls for service when one or more machines are already waiting, a portion of the total time it waits for service may be attributed to the fact of waiting on the part of those machines which gave prior calls), the cumulative effect of even small variations in service time and or machine time can soon throw such a process into essentially random variation.

Where machine assignment tends to be large, calls for service frequent, and service time short relative to machine time, a process assumes essentially random characteristics with regard to calls for service. Even where these characteristics are not present in any great degree, calls for service often occur according to some probability distribution which may be discovered. Throughout this paper the assumption is made that calls for service from a group of n machines are distributed individually and collectively at random.

When synchronization is possible due to very stable machine time and service time, the problem of assignment is simple,[2] but in that large number of cases where waiting time does occur, economic assignment depends oh the ability to predict the expected magnitude of this time. The economic problem is that of determining the assignment which minimizes the cost of a given output recognizing the fact that, in general, waiting time can be reduced by a smaller assignment but this smaller assignment increases the labor cost. Furthermore, account must be taken of the fact that a decrease (increase) in waiting time effects a corresponding increase (decrease) in machine time according to the relation between service time and machine time.

In the first part of this paper the economic assignment problem will be treated under the assumption that the expected waiting time can be determined for any class of machines. Then, in the second part, various methods which have been devised for making this determination will be presented and evaluated so that a selection of that method best in a given situation may be made. Tables will be presented from which waiting time values may be read directly. Finally, recommendations will be made as to the mathematical and industrial research necessary both for this application and to extend the concept to problems in industry of similar physical structure.

In view of the diversity of terms and definitions which occurs in the literature, a single set of symbols will be adopted with consistent meanings throughout.

Symbols and Definitions

s = service time per time unit.
m = machine running time per time unit.
w = waiting time per time unit.
λ = calls for service per unit of machine time (expected value).
μ = machines serviced per unit of service time (expected value).
$k = s/m = \lambda/\mu$ = servicing constant.
n = number of machines assigned to r operators.
n_e = economic assignment ($n_e = n$ when C_u is a minimum).
r = number of operators.
p_ν = state variable, where ν refers to the number of machines requiring service in the state whose probability is p.
$1 - p_0$ = degree of worker utilization.
C = total cost of machine operation per time unit per machine.
C_m = cost of machine running time per time unit per machine.
C_s = cost of service time per time unit per machine (excluding labor).
C_w = cost of waiting time per time unit per machine.
C_o = cost of output per time unit per machine.
C_r = cost of operator per time unit.

The costs which are important to this problem as will be shown later are C_w and C_r. The cost of waiting time often presents some difficulty since it represents productive time which is lost through an avoidable cause. Thus, its cost must be evaluated in terms of that which is foregone by allowing it to occur. If only output is lost with no repercussions on sales, dealer relations, or the like, this cost may be assumed to be equal to the value of the lost output. If there are external effects, these must be accounted for in assigning a value to C_w.

The servicing constant, k, is subject to various equivalent definitions in physical terms. The basic machine property which it describes is the ratio of λ to μ. The probability that a machine will call for service in an interval dt under the assumption that such calls are distributed individually and collectively at random is shown by Palm[3] (2) to be λdt plus negligible terms where λ is the expected value of calls for service per unit of machine time and is physically equivalent to the inverse value of the mean machine time, m. Similarly, the probability that a machine will be put back in service in an interval dt can be shown to be μdt plus negligible terms where μ is the expected number of machines serviced per unit of service time and is physically equivalent to the inverse value of the mean service time. The servicing constant is:

$$k = \frac{\lambda}{\mu} = \frac{m^{-1}}{s^{-1}} = \frac{s}{m},$$

where the units of machine and service time are equivalent physically.

Four physical interpretations of this constant appear from the above. For example, k may be easily determined when a machine of the type in question can be serviced under conditions where no waiting time occurs, i.e., one machine serviced by one operator. Then k is equivalent to the total service time divided by the total machine time. The determination of the servicing constant under

[2] In such a case, the machine assignment, n, is equal to the total time divided by the service time where total time does not include any operator allowances.

[3] Thanks are due to Mr. Gunnar Dannerstedt of M.I.T. for his services in translating this article.

conditions where waiting time can occur tends to be more difficult. It can often be satisfactorily accomplished by the ratio-delay method or by recording total time expended in connection with machine operation over a period and separating out service times and machine times. The period recorded must be long enough so that the values of s and m obtained from averaging can be accepted with some confidence as being expected values.

The Economics of Assignment: Single Serviceman

The total cost per time unit per machine when a battery of n machines is serviced by one operator is

$$C = mC_m + sC_s + wC_w + \frac{C_r}{n} \qquad \text{Eq. (1)}$$

where the operator has no auxiliary duties which interfere with his servicing of the machines whenever such service is required. Assuming that output occurs only during m,[4] the cost of this output is

$$C_o = \frac{C}{m}.$$

Substituting in (1),

$$C_o = C_m + \frac{s}{m}C_s + \frac{w}{m}C_w + \frac{1}{mn}C_r = C_m + kC_s + \frac{WC_w + C_r/n}{m} \qquad \text{Eq. (2)}$$

Assuming that our objective is to minimize C_o with respect to n,[5] the machine assignment, and since only w and m vary in (2), that n which minimizes the third term in (2) is the economic assignment. Since w and m depend on n, no explicit solution can be obtained for this minimum, but a relatively simple tabular solution is possible according to the form given by Table 1. Tables of w and m for various k and n are given later for the case where an operator services n machines under the assumption of either constant or an exponential distribution of service times.

In Table 1, an example is given of the use of these data where $k = 0.08$, $C_w = \$10$ hour, and $C_r = \$2$ hour. In some situations C_w may vary in some way with variations in m. In such cases the values entered in column (3) of the table should reflect this variation. Column (7) gives the variable cost associated with the machine assignments in column (1) while column (8) gives the proportion of total time during which the operator will be busy where no personal or delay allowances are included.

Palm (3) and Ashcroft (4) give solutions where essentially the last term of equation (2) is determined at

[4] The situation where output occurs during m and s is treated later.

[5] This objective is equivalent to one of profit maximization when output and price are constant. In this case, output varies according to w, and w in turn varies according to n. The implicit assumption made, then, is that the value of a unit of output is constant over the range of outputs experienced in each situation. Thus, it is considered essential to include both m and w when evaluating the alternative assignments. The fact of changing m must always be taken into account when making an assignment.

TABLE 1*

(1) n	(2) w	(3) WC_w	(4) C_r/n	(5) (3) + (4)	(6) m	(7) (5)/(6)	(8) $1 - p_0$
1	0.000	0	$2.00	$2.00	.926	$2.16	.074
2	0.005	$0.05	1.00	1.05	.921	1.14	.147
3	0.012	0.12	.67	.79	.915	.86	.220
4	0.019	0.19	.50	.69	.909	.76	.291
5	0.027	0.27	.40	.67	.901	.74	.361
6	0.035	0.35	.33	.68	.893	.76	.429
7	0.045	0.45	.29	.74	.884	.84	.495
8	0.057	0.57	.25	.82	.873	.94	.559
9	0.070	0.70	.22	.92	.861	1.07	.620
10	0.085	0.85	.20	1.05	.848	1.24	.678

* The values for w, m, and $1 - p_0$ are for the given k under the assumption that calls for service and service times are distributed exponentially according to $\lambda te^{-\lambda t}$ and $\mu te^{-\mu t}$ respectively.

that point where n_e changes to $n_e + 1$. At this point the condition that the last term in equation (2) be a minimum is satisfied for

$$\frac{WC_w + C_r/n_e}{m} = \frac{w'C_w + C_r/(n_e + 1)}{m'} \qquad \text{Eq. (3)}$$

where w and m are determined at n_e and w' and m' at $n_e + 1$. Limiting values of the ratio of C_w to C_r may be obtained for various k. The loci of such points for equal n will give the boundaries of areas for all n_e. The difficulty here is that no information is available from such a graph as to the relative effect of different assignments in terms of variable costs, operator utilization, and available machine time.

The effect of varying the assignment away from n_e in Table 1 may be easily seen. This becomes important in that large number of cases where n_e does not correspond to the necessities of a given situation, e.g., where seven machines must be assigned and n_e is as given in Table 1. In this case the alternative assignments may be easily examined as regards their relative costs, degree of operator utilization, and machine running time. This is especially important where an operator may be assigned auxiliary duties during the time represented by the state p_0, i.e., when no machines are in service.

In situations where production occurs during $m + s$,

$$C_o = \frac{C}{m+s} = \frac{m}{m+s}C_m + \frac{s}{m+s}C_s + \frac{WC_w + C_r/n}{m+s}. \qquad \text{Eq. (4)}$$

Since

$$k = \frac{s}{m},$$

then

$$\frac{m}{m+s} = \frac{1}{1+k}$$

and

$$\frac{s}{m+s} = \frac{k}{1+k}.$$

Also, from the definition of k and the assumption that the sum of machine time, service time, and waiting time equals total time,

$$m + s = m(1 + k) = 1 - w$$

Substituting in (4),

$$C_v = \frac{1}{1+k}(C_m + kC_s) + \frac{WC_w + C_r/n}{1-w}. \qquad \text{Eq. (5)}$$

Again, the last term represents variable costs associated with each machine assignment, n, and is to be minimized with respect to n. In order to determine n_e, it is only necessary to substitute $1 - w$ for m in Column (6) of the table.

The Economics of Assignment: Collaborating Servicemen

The work by Palm also treats the situation where it is possible that operators may collaborate in servicing a number of machines. In general, this kind of solution gives less waiting time for a given average assignment than the case of one operator assigned to n machines. This general conclusion assumes that the make-ready and walking times necessary in the case where operators collaborate is not materially greater than in the case of no collaboration.

In these cases, the only difference in the entries in the table are the values of m, w, and the degree of worker utilization which must be obtained for each alternative with regard to collaboration, and C_r which must be multiplied by the number of collaborating workers.

Palm gives the method of computation for these cases, but no general tables are available. A set of formulas for determining w, m, and the degree of worker utilization under conditions of collaboration is given in a later section. The method used assumes an exponential distribution of service times.

In order to determine the amount of collaboration which will yield a minimum C_v in a given situation, the various alternatives available must be determined and a table as in our previous example computed for each number of collaborating operators. In general, however, the most economical case will be that for which the number of machines serviced by collaborating workers is the largest number available in a single location. This assumes that k is not materially affected by walking times and that workers are willing to collaborate (arguments as to who shall service the machine which just called for service are assumed not to occur). For this case it is only necessary to prepare a table according to Table 2.

A comparison of Tables 1 and 2 reveals considerable gains in those cases where collaboration between operators is physically feasible. With the same servicing constant and costs, Table 2 indicates that two collaborating operators for 20 machines can achieve approximately the same variable cost per hour of output per machine as four non-collaborating operators ($n = 5$ in Table 1). However, this is only accomplished with a reduction in available machine time from 90.1% to 88.3% of total time. Also, the free time of each operator is reduced from 64% to 29%.

TABLE 2

$k = 0.08$, $n = 20$, $C_w = \$10$/hour, $C_r = \$2$/hour/operator

(1) r	(2) w	(3) WC_w	(4) rC_r/n	(5) (3) + (4)	(6) m	(7) (5)/(6)	(8) $1 - p_0$
2	.046	$0.46	$0.20	0.66	.883	$0.75	.707
3	.010	0.10	0.30	0.40	.917	0.44	.491
4	.004	0.04	0.40	0.44	.922	0.48	.369

When three operators are assigned to the 20 machines a reduction in variable costs of $.30 per hour of output per machine is achieved with an increase from 90.1% to 91.7% in available machine time. At the same time, operator utilization shows an increase from 36.1% to 49.1%. In all cases, of course, the assignment must be modified if any value should be attached to the free time of the operators.

When collaboration is being considered, attention must be paid to the walking times involved in the larger assignments which result. When assignment is small, the walking times do not usually influence k to any appreciable extent, but when the assignment is large k may have to be revised upward to account for this mean addition to service time (and consequent reduction in available machine time).

The Determination of Waiting Time

In the preceding examples of economic assignment, the method presented by Palm was used in determining waiting times, machine availability, and degree of operator utilization. Since 1933[6] (5), methods for determining waiting time of machines have been reported and these will be examined in essentially chronological order.

Wright (6) uses Fry's (7) formula for determining the expected delay in servicing a telephone call where a limited number of telephone lines are serviced by a single trunk line under the following assumptions:

1. A group of telephone lines having access to one trunk line are handled so that if a call requiring the use of this line originates while a call is already using the trunk, the second call will be delayed until the first call is finished.
2. All calls are of equal duration.
3. The calls which are assigned to the group of channels are distributed individually and collectively at random.

In our symbols, Wright finds

$$I = 0.50[\sqrt{(1 + k^{-1} - n)^2 + 2n} - (1 + k^{-1} - n)]$$

Eq. (6)

[6] A. J. Khintchine derived a solution to this problem which according to Benson and Cox (see Bibliography) essentially parallels both the Palm and Asheroft solutions. The values given in Table 4 for a Pearson Type III distribution of service times ($V = 0.5$) were obtained from Khintchine's solution. A translation of this paper was not available, and it is assumed to be as reported by Benson and Cox.

where

$$I = \frac{w}{s}.$$

In order to get a solution for w, the waiting time, it is necessary to assume that

$$m + s + w = 1, \qquad \text{Eq. (7)}$$

that is, that the sum of machine time, service time, and waiting time is the total time available. Since

$$m = sk^{-1}$$

and

$$w = Is,$$

then

$$Is + s + sk^{-1} = 1$$

and

$$s = \frac{1}{I + k^{-1} + 1}.$$

Substituting in (7), we get

$$w = \frac{I}{I + k^{-1} + 1}. \qquad \text{Eq. (8)}$$

Results of this formula for $k = 0.10$ appear in column (1) of Table 3 where the results given in parentheses are those actually used by Wright for machine assignments up to six. These latter values were given as empirically determined since computed values did not agree with observations in this range.

Since Wright begins with a formula for average delay per call (average waiting time per service period in the machine case), this result should not be unexpected. Waiting time is determined by multiplying this average delay by the expected number of calls. Thus, a value for waiting time is obtained for $n = 1$ when, in fact, no waiting time can occur. This bias is important as long as n is small. Even so, Wright does provide us with important empirical evidence since his computed values were checked against actual observations.

Duvall (8) devised an empirical formula in work at the Western Electric Company, Incorporated. The assumptions made are as follows:

1. Calls for service occur individually and collectively at random.
2. All machines assigned to a single operator are identical.
3. The operator is equally available to all machines.
4. The servicing operation is always the same but the time required for such service may vary.

The equation given is

$$I = (n - 1)e^{-1.4k^{-1}n^{-0.946}} \qquad \text{Eq. (9)}$$

where

$$I = \frac{w}{s}.$$

As in the Wright method,

$$w = \frac{I}{I + k^{-1} + 1}.$$

Duvall reports that the relationship

$$I = ce^{ak^{-1}}$$

where c and a are constants varying with n was determined to be appropriate for this problem by observation and reasoning on the nature and characteristics of I (interference). Further reasoning leads to a value of $n - 1$ for c (since the I-axis intercept of a family of curves in I and k^{-1} for a given n is $n - 1$)[7] and of $-1.4n^{-0.946}$ for a (deduced from empirical data). As shown in column (2) of Table 3, Duvall's formula gives very low values of w for small n with a rapid increase after $n = 5$ for the case where $k = 0.1$.

Palm (9) gives a solution under the following assumptions:

1. Calls for service occur at random intervals with an expected frequency λ.
2. Each call will be serviced immediately by any free operator.
3. Service times are distributed independently according to an exponential distribution with expected value $s(k) = \lambda s$.

His treatment results in (10)

$$w = 1 - s(1 + k^{-1}) \qquad \text{Eq. (10)}$$

where

$$s = \frac{1 - p_0}{n},$$

$$p_0 = \frac{1}{\sum_{\nu=0}^{n} \frac{p_\nu}{p_0}}, \qquad \text{Eq. (11)}$$

$$\sum_{\nu=0}^{n} p_\nu = 1, \qquad \text{Eq. (12)}$$

and

$$p_\nu = \frac{n!}{(n - \nu)!} k^\nu p_0. \qquad \text{Eq. (13)}$$

These formulas make it possible to compute values for waiting time, service time, machine time [from (17)], and degree of operator utilization under the given assumptions. Palm gives tables of w, m, and $1 - p_0$ for values of k from .01 to .40 for this case.

Palm also derives a solution for the case where r operators attend n machines. In this case, the same assumptions are made as for a single operator. The computations, however, are somewhat more difficult, as

$$w = \frac{\sum_{\nu=r+1}^{n} (\nu - r)p_\nu}{n} \qquad \text{Eq. (14)}$$

[7] Note that Duvall did not make the error of showing waiting time when $n = 1$ as did Wright as reported above.

where the p may be determined from

$$p_1 = nkp_0, \qquad \text{Eq. (15)}$$

$$p_\nu(\nu \leq r) = (n - r + 1)kp_{\nu-1/\nu}, \qquad \text{Eq. (16)}$$

$$p_\nu(\nu > r) = (n - \nu + 1)kp_{\nu-1/r}, \qquad \text{Eq. (17)}$$

and

$$\sum_{\nu=0}^{n} p_\nu = 1. \qquad \text{Eq. (18)}$$

With (15), (16), and (17) all the state variables, p, may be given in terms of p_0. Then using (18), p_0 may be calculated and thus all the p determined. Palm does not give tables for w, m, and degree of operator utilization in these cases. Values of the latter two may be computed from

$$m = \frac{1 - w}{1 + k} \qquad \text{Eq. (19)}$$

and

$$p = \frac{\sum_{\nu=0}^{r-1} (r - \nu)p_\nu}{r} \qquad \text{Eq. (20)}$$

where p is the degree of operator utilization.

Ashcroft (11) derives a general solution for determining waiting times under the following assumptions:

1. The probability of a particular machine calling for service within a short period does not depend on the state of the other machines.
2. The probability of a call for service does not depend on the time which has elapsed since it last gave a call for service.

The results obtained are quite general and depend only on introducing the proper service time distribution. For example, when an exponential distribution is assumed, this solution becomes equivalent to that given by Palm, and

$$Y_N = 1 + (n - 1)k + (n - 1)(n - 2)k^2 + \cdots$$
$$\cdots + (n - 1)!k^{n-1} \qquad \text{Eq. (21)}$$

where the average number of machines running is

$$A_N = k + (nY_N)^{-1} \qquad \text{Eq. (22)}$$

and

$$w = 1 - \frac{A_N}{n}(1 - k). \qquad \text{Eq. (23)}$$

When service times are assumed constant,

$$Y_N = 1 + \binom{n-1}{1}(e^k - 1) + \binom{n-1}{2}(e^k - 1)(e^{2k} - 1) + \cdots \qquad \text{Eq. (24)}$$

Ashcroft gives tables of A_N for this latter case and these values are used in computing column (3) of Table 3.

Benson and Cox (12) give a solution to this problem in the case where r operators specialize each in one of r types of stoppage. For $r = 2$,

TABLE 3

Waiting Time Values, $k = 0.10$

n	(1) Wright	(2) Duvall	(3) Ashcroft	(4) Khintchine	(5) Palm
1	.005 (.000)	.000	.000	.000	.000
2	.009 (.004)	.000	.004	.005	.008
3	.016 (.009)	.001	.010	.012	.018
4	.024 (.017)	.006	.016	.019	.028
5	.034 (.027)	.017	.023	.028	.041
6	.047 (.047)	.034	.032	.039	.055
7	.063	.056	.044	.051	.071
8	.083	.083	.058	.067	.090
9	.108	.122	.075	.086	.112
10	.140	.144	.097	.109	.136
11	.175	.176	.124	.136	.163
12	.214	.209	.156	.167	.193
13	.254	.239	.192	.202	.225
14	.292	.273	.233	.240	.259
15	.329	.302	.274	.279	.294

$$m = \frac{F(k_1, n) - F(k_2, n)}{F(k_1, n + 1) - F(k_2, n + 1)} \qquad \text{Eq. (25)}$$

and

$$w = 1 - m(1 - k), \qquad \text{Eq. (26)}$$

where

$$F(k, n) = \sum_{\nu=0}^{n} \frac{p_\nu}{p_0} \qquad \text{Eq. (27)}$$

as shown in the solution derived by Palm, and

$$k_1 = \frac{\lambda_1}{\mu_1},$$

$$k_2 = \frac{\lambda_\nu}{\mu_\nu}.$$

The computational difficulties involved in this solution are quite clear. As the number of service types becomes large, these difficulties are compounded. Machine solution could be made where this is economically justified. However, unless there is a wide disparity in the λ_i and μ_i; it appears realistic to assume that service calls and service times each come from a single universe wherein all values are pooled (13).

Comparison of Results

A comparison of results obtained from the methods[8] of Ashcroft, Duvall, Khintchine, Palm, and Wright is given in Table 3 for $k = 0.10$. As noted previously the Khintchine results assume that service times vary according to a Pearson Type III distribution (whose coefficient of variation = 0.5). The inference here is that empirical data (Wright and Duvall) indicate that for the cases which they considered, the assumption of constant service time for low n and an exponential distribution

[8] No results are given for those methods involving an assumption that the binomial distribution may be used to determine waiting times. The methods portrayed are considerably less restrictive in their assumptions. Also, the methods of Field and Stout (see Bibliography) are similarly not included.

TABLES OF WAITING TIME AND MACHINE AVAILABILITY FOR SELECTED SERVICING CONSTANTS*†

(Values expressed as percentages of total time where m + s + w = 100%)

n	(a)		(b)	
	w	m	w	m
k = 0.01				
1	0.0	99.0	0.0	99.0
10	0.1	99.0	0.1	98.9
20	0.1	98.9	0.2	98.8
30	0.2	98.8	0.4	98.6
40			0.6	98.4
50			0.9	98.1
60			1.3	97.8
70			1.8	97.2
80			2.7	96.3
85			3.4	95.7
90			4.2	94.9
95			5.2	93.8
100			6.7	92.4
105			8.5	90.6
110			10.7	88.4
115			13.4	85.8
120			16.3	82.9
121			16.9	82.3
122			17.5	81.7
123			18.1	81.1
124			18.8	80.4
125			19.4	79.8
126			20.0	79.2
127			20.6	78.6
128			21.2	78.1
129			21.8	77.5
130			22.4	76.9
131			22.9	76.3
132			23.5	75.7
133			24.1	75.2
134			24.6	74.6
135			25.2	74.1
136			25.7	73.5
137			26.3	73.0
138			26.8	72.5
139			27.3	71.9
140			27.9	71.4
141			28.4	70.9
142			28.9	70.4
143			29.4	69.9
144			29.9	69.4
k = 0.02				
1	0.0	98.0	0.0	98.0
5	0.1	98.0	0.2	97.9
10	0.2	97.8	0.4	97.6
15	0.4	97.7	0.7	97.4
20	0.6	97.5	1.1	97.0
25	0.8	97.2	1.6	96.5
30	1.2	96.9	2.2	95.9
35			3.1	95.0
40			4.3	93.8
45			6.1	92.0
50			8.7	89.5
51			9.3	88.9
52			10.0	88.3
53			10.7	87.6
54			11.5	86.8
55			12.3	86.0
56			13.1	85.2
57			14.0	84.3
58			14.9	83.4
59			15.9	82.5
60			16.8	81.5
61			17.9	80.5
62			18.9	79.5
63			19.9	78.5
64			21.0	77.5
65			22.0	76.4
66			23.1	75.4
67			24.2	74.4
68			25.2	73.3
69			26.2	72.3
70			27.2	71.3
71			28.2	70.4
72			29.2	69.4
k = 0.03				
1	0.0	97.1	0.0	97.1
5	0.2	96.9	0.4	96.7
10	0.5	96.6	1.0	96.2
15	1.0	96.2	1.8	95.4
20	1.6	95.5	3.0	94.2
25	2.8	94.4	4.7	92.5
26	3.1	94.1	5.2	92.1
27	3.4	93.7	5.7	91.6
28	3.8	93.4	6.2	91.1
29	4.3	92.9	6.8	90.5
30	4.8	92.4	7.4	89.9
31			8.1	89.2
32			8.9	88.5
33			9.7	87.7
34			10.6	86.8
35			11.6	85.9
36			12.6	84.9
37			13.7	83.8
38			14.9	86.8
39			16.1	81.4
40			17.4	80.2
41			18.8	78.9
42			20.1	77.5
43			21.6	76.2
44			23.0	74.8
45			24.4	73.4
46			25.9	72.0
47			27.3	70.6
48			28.7	69.2
k = 0.04				
1	0.0	96.2	0.0	96.2
2	0.1	96.1	0.2	96.0
3	0.2	96.0	0.3	95.9
4	0.2	95.9	0.5	95.7
5	0.3	95.8	0.7	95.5
6	0.5	95.7	0.9	95.3
7	0.6	95.6	1.1	95.1
8	0.7	95.5	1.3	94.9
9	0.8	95.4	1.5	94.7
10	1.0	95.2	1.8	94.4
11	1.1	95.1	2.1	94.1
12	1.3	94.9	2.4	93.8
13	1.5	94.7	2.8	93.5
14	1.8	94.5	3.2	93.1
15	2.0	94.2	3.6	92.7
16	2.3	94.0	4.0	92.3
17	2.6	93.6	4.5	91.8
18	3.0	93.3	5.1	91.3
19	3.4	92.9	5.7	90.7
20	3.9	92.4	6.4	90.0
21	4.5	91.8	7.1	89.3
22	5.2	91.2	8.0	88.5
23	6.0	90.4	8.9	87.6
24	6.8	89.6	9.9	86.7
25	7.9	88.6	11.0	85.6
26	9.0	87.5	12.2	84.5
27	10.4	86.2	13.4	83.2
28	11.9	84.7	14.8	81.9
29	13.6	83.0	16.3	80.5
30	15.5	81.3	17.9	79.0
31			19.6	77.4
32			21.3	75.7
33			23.0	74.0
34			24.8	72.3
35			26.6	70.6
36			28.4	68.9
37			30.1	67.2
k = 0.05				
1	0.0	95.2	0.0	95.2
2	0.1	95.1	0.2	95.0
3	0.2	95.0	0.5	94.8
4	0.4	94.9	0.7	94.5
5	0.5	94.7	1.0	94.3
6	0.7	94.6	1.4	94.0
7	0.9	94.4	1.7	93.6
8	1.1	94.2	2.1	93.3
9	1.4	93.9	2.5	92.9
10	1.6	93.7	3.0	92.4
11	2.0	93.4	3.5	91.9
12	2.3	93.0	4.1	91.4
13	2.7	92.6	4.7	90.8
14	3.2	92.2	5.4	90.1
15	3.8	91.7	6.2	89.3
16	4.4	91.0	7.1	88.5
17	5.2	90.3	8.1	87.6
18	6.1	89.5	9.1	86.5
19	7.1	88.5	10.4	85.4
20	8.4	87.3	11.7	84.1
21	9.8	85.9	13.1	82.7
22	11.5	84.3	14.7	81.2
23	13.4	82.5	16.5	79.6
24	15.5	80.5	18.3	77.8
25	17.8	78.2	20.2	76.0
26	20.3	75.9	22.2	74.1
27	22.8	73.6	24.3	72.1
28	25.3	71.2	26.4	70.1
29	27.9	68.8	28.5	68.1
k = 0.06				
1	0.0	94.3	0.0	94.3
2	0.2	94.2	0.3	94.0
3	0.4	94.0	0.7	93.7
4	0.6	93.8	1.1	93.3
5	0.8	93.6	1.5	92.9
6	1.1	93.3	2.0	92.5
7	1.4	93.1	2.5	92.0
8	1.7	92.7	3.1	91.4
9	2.1	92.4	3.7	90.8
10	2.6	91.9	4.5	90.1
11	3.1	91.4	5.3	89.4
12	3.8	90.8	6.2	88.5
13	4.5	90.1	7.3	87.5
14	5.4	89.2	8.4	86.4
15	6.5	88.2	9.7	85.2
16	7.8	87.0	11.2	83.8
17	9.3	85.6	12.8	82.3
18	11.1	83.9	14.6	80.6
19	13.2	81.9	16.5	78.8
20	15.6	79.7	18.6	76.8
21			20.8	74.7
22			23.1	72.5
23			25.5	70.3
24			27.9	68.0
25			30.3	65.8
k = 0.07				
1	0.0	93.5	0.0	93.5
2	0.2	93.2	0.4	93.1
3	0.5	93.0	0.9	92.6
4	0.8	92.7	1.4	92.1
5	1.1	92.4	2.0	91.6
6	1.5	92.1	2.7	91.0
7	1.9	91.7	3.4	90.3
8	2.4	91.2	4.3	89.5
9	3.1	90.6	5.2	88.6
10	3.8	89.9	6.3	87.6

* All tables assume random calls for service. Column (a) is for constant servicing time and column (b) for an exponential distribution of servicing times. It is hoped that the missing values in column (a) can be secured by approximation in the near future.

† Where no entry appears in column the figures were not available.

TABLES OF WAITING TIME AND MACHINE AVAILABILITY FOR SELECTED SERVICING CONSTANTS*† (*continued*)

n	(a)		(b)	
	w	m	w	m
	$k = 0.07$ (*cont.*)			
11	4.7	89.1	7.5	86.4
12	5.7	88.1	8.9	85.1
13	7.0	86.9	10.4	83.7
14	8.6	85.4	12.2	82.1
15	10.4	83.7	14.1	80.3
16	12.6	81.6	16.2	78.3
17	15.2	79.3	18.5	76.2
18	18.1	76.6	21.0	73.9
19	21.1	73.7	23.5	71.5
20	24.4	70.7	26.2	69.0
21			28.9	66.5
	$k = 0.08$			
1	0.0	92.6	0.0	92.6
2	0.3	92.3	0.5	92.1
3	0.6	92.0	1.2	91.5
4	1.0	91.7	1.9	90.9
5	1.4	91.2	2.7	90.1
6	2.0	90.8	3.5	89.3
7	2.6	90.2	4.5	88.4
8	3.4	89.5	5.7	87.3
9	4.3	88.6	7.0	86.1
10	5.4	87.6	8.5	84.8
11	6.7	86.4	10.1	83.2
12	8.4	84.8	12.0	81.4
13	10.4	83.0	14.2	79.5
14	12.8	80.8	16.5	77.3
15	15.6	78.2	19.0	75.0
16	18.8	75.2	21.8	72.4
17	22.2	72.0	24.6	69.8
18	25.7	68.8	27.6	67.1
19	28.2	66.5	30.5	64.4
	$k = 0.09$			
1	0.0	91.5	0.0	91.7
2	0.4	91.4	0.7	91.1
3	0.8	91.0	1.4	90.4
4	1.3	90.6	2.3	89.6
5	1.9	90.0	3.3	88.7
6	2.6	89.4	4.5	87.7
7	3.4	88.6	5.8	86.5
8	4.5	87.6	7.3	85.1
9	5.7	86.5	9.0	83.5
10	7.3	85.0	10.9	81.7
11	9.3	83.2	13.1	79.7
12	11.7	81.0	15.6	77.5
13	14.5	78.4	18.3	75.0
14	17.8	75.4	21.2	72.3
15	21.5	72.0	24.2	69.5
16	25.3	68.5	27.4	66.6
17	29.2	65.0	30.6	63.7
	$k = 0.10$			
1	0.0	90.9	0.0	90.9
2	0.4	90.5	0.8	90.2
3	1.0	90.0	1.8	89.3
4	1.6	89.5	2.8	88.3
5	2.3	88.8	4.1	87.2
6	2.2	88.0	5.5	85.9
7	4.4	86.9	7.1	84.4
8	5.8	85.7	9.0	82.7
9	7.5	84.1	11.2	80.8
10	9.7	82.1	13.6	78.5
11	12.4	79.8	16.3	76.1
12	15.6	76.8	19.3	73.4
13	19.2	73.4	22.5	70.4
14	23.3	69.8	25.9	67.4
15	27.4	66.0	29.4	64.2
16	31.5	62.0		
	$k = 0.15$			
1	0.0	87.0	0.0	87.0
2	0.9	86.2	1.7	85.5
3	2.1	85.1	3.6	83.8
4	3.9	83.8	6.0	81.8
5	5.5	82.2	8.7	79.4
6	8.0	80.0	11.8	76.7
7	11.2	72.2	15.4	73.5
8	15.2	73.7	19.5	70.0
9	20.1	69.5	23.8	66.2
10	25.5	64.8	28.4	62.3
11	31.0	60.0		
	$k = 0.20$			
1	0.0	83.3	0.0	83.3
2	1.5	82.0	2.7	81.1
3	3.6	80.4	5.9	78.4
4	6.3	78.1	9.8	75.2
5	10.0	75.0	14.2	71.5
6	14.7	71.1	19.2	67.4
7	20.6	66.2	24.6	62.8
8	27.3	60.6	30.3	58.1
9	32.6	56.1		
	$k = 0.30$			
1	0.0	76.9	0.0	76.9
2	3.0	74.6	5.1	73.0
3	7.4	71.3	11.1	68.4
4	13.3	66.7	18.0	63.1
5	21.1	60.7	25.4	57.4
6	29.9	53.9	33.0	51.6
	$k = 0.40$			
1	0.0	71.4	0.0	71.4
2	4.8	68.0	7.5	66.0
3	11.8	63.0	16.3	59.8
4	21.2	56.3	25.6	53.1
5	31.9	48.6	34.9	46.5

for high n (the breaking point occurring at $n = 6$ in this case) seems justified. In any case, the extreme cases considered by Ashcroft (C.V. = 0) and Palm (C.V. = 1) with regard to service time distribution when compared with available empirical data and the Khintchine results (C.V. = 0.5) lead one to believe that a decision based on the coefficient of variation of service times even with only two choices available may be quite practical. Thus, when the coefficient of variation for the distribution of service times is near 1, the Palm tables may be used for w; and when the coefficient of variation is between 0 and 0.6 or 0.7, Ashcroft numbers will give satisfactorily accurate results for w. It should also be noted that interpolation between the Palm and Ashcroft results according to the square of the coefficient of variation of the service time distribution yields good results for waiting time.

It is to be hoped that a family of curves for the distribution of service times covering a greater number of situations than these two extremes can be discovered and results tabled. The tables included with this paper give w and m according to the Palm and Ashcroft solutions. The degree of worker utilization may be computed from

$$1 - p_0 = nkm. \qquad \text{Eq. (28)}$$

It is realized that the tables are quite incomplete for the constant servicing time assumption; but the computational difficulties here are very significant.

Conclusions

It seems clear from the work already done on applications of waiting line theory (14) that its potentialities in industrial use are just beginning to be realized. The computational difficulties so apparent in the methods reported above are beginning to be overcome with high speed computers, but some major areas for research are still relatively untouched.

Work must be done in industry on the problem of defining areas of application in terms of servicing requirements and capabilities. Machine repair seems an obvious area in this connection, but almost nothing has been done to verify the possibilities. Further, having defined a possible area of application, it is then necessary to determine empirically the probability distributions associated with servicing requirements and with servicing times. If important distributions not heretofore treated appear, then ways must be discovered to handle these within the mathematical framework of the basic waiting line problem.

As indicated previously, a single family of curves covering a majority of situations would constitute an ideal solution. In any case it is clear that empirical verification of the probabilities in various applications is essential to significant progress with the theory. Hopefully, evidence of this kind can appear from trial applications in the

machine assignment situation. Other applications may be suggested through familiarity with the servicing concept and a specific industrial environment. Feedback of such information through publications, to universities, and to other interested research agencies is essential to progress in this area.

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Merit Rating—for Frill or for Function?

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Merit rating, in a loose and general sense, exists whenever two people have a contact with one another. The activity of one is evaluated by the other, and this evaluation may not even be on a strong, conscious level. Merit rating, as discussed in this paper, is a deliberate mechanism which seeks to encourage the more thoughtful application of the evaluative process and by so doing improve the productive effort of existing personnel.

Definition:

Merit rating, a tool of management, is the scientific approach to periodic evaluation of an individual's capacity to do a job, and his performance in the given job situation.

Purpose:

Fair and equitable interpretation of the merit rating procedure permits the application of the following list of overall purposes:

"1. To help in deciding who should be promoted, demoted, or given a raise in pay.
2. To discover workers' weaknesses as a basis for planning training.
3. To uncover exceptional talents.
4. To furnish a basis for discharge of totally unfit employees.
5. To help top supervisors learn how each person is appraised by his foreman.
6. To help top supervisors judge the fairness, severity, or leniency with which supervisors judge their people.
7. To help in assigning work in accordance with workers' ability.
8. To serve as a check on employment procedures generally, and interviews and tests specifically.
9. To stimulate people to improve.
10. To develop people's morale through stimulating confidence in management's fairness." (1)

Perhaps one of the difficulties in the administration of any merit rating plan is the full recognition of these ten purpose-elements by the three parties of the social triangle of the business enterprise—management, supervisor, and employee. All too frequently the plan fails for lack of understanding.

There are any number of types of merit rating formats. Each type has its value and application. By far, the reason for the success or failure of any plan is not necessarily the plan itself, but rather the actual administration of the plan. Suspicion and rumor, unchecked and based on the absence of qualified and factual information, have ruined merit rating systems which might otherwise have been beneficial and perpetual for the business enterprise.

Postulates:

Within the framework of the ten purpose-elements just cited, active approval-participation involving the following four essentials must be clearly in evidence to ensure the well-working merit rating program:

1. The company policy must be stated and consistent so that the merit rating procedure becomes a functioning, perpetual activity. The drive-force must not

be allowed to deteriorate into a half-hearted attempt at evaluation or be utilized as a subterfuge to cover some exploitive mechanism.

2. The rater must understand the purpose of the merit rating procedure, must understand his function, and must be trained in the administration of the procedure.
3. The ratee must be clearly aware of the purpose of the merit rating procedure, must realize that he has a definite stake in the outcome, and agree that it is distinctly to his advantage to be appraised.
4. The final evaluation, as submitted by the rater, is the result of a shared discussion and estimate of the situation. The conference of the rater and the ratee should be a private, unhurried meeting.

Answerable Questions:

The business enterprise is made up of materials, machines, and people. The investigations and tasks carried out by the several departments (planning, engineering, scheduling, methods & procedures, time & motion study, production control, quality control, inspection, purchasing, receiving, shipping, maintenance—all those which go to make up the enterprise, whether it be for manufacturing, research, marketing or confined solely to office and clerical functions) seek greater efficiency through the physical tools and implements with which people work. Merit rating, since its application suggests further areas of investigation, that of the realm of human relationships (people with people, and people with their work environment), can serve to provide replies to many of the following questions:

"1. How are they doing on their jobs? Do they measure up to the standards we need to produce a high-quality product at competitive prices?
2. What are their weaknesses so we can help them improve?
3. What are their strengths so we can make full use of them?
4. Apart from just doing their work, do they fit in generally with our way of doing things?
5. Are they getting ahead as fast and as far as their ability will take them?" (2)

Merit rating, as outlined in this paper, can be a handy tool for management to use to obtain valuable and useful answers to these questions.

Who Should Rate:

The question of who should do the formal rating always arises. Although there are three possible parties—the ratee's immediate supervisor (perhaps even the supervisor's supervisor too, but separately, if he knows the ratee and this would increase the number to four), the ratee's peers (not recommended for lower economic bracket employees of the shops or assembly line variety), or the ratee's subordinates (sometimes used by the military)—who might do the rating, the almost universal practice is to have the immediate supervisor do the rating.

Evaluation Conference:

The evaluation conference between the rater and ratee can serve to bring out into the open the multitude of social aspects, the interpersonal relationships and interchanges within the plant or business daily life, which do affect productivity of the employee:

"1. Job performance can be improved by letting the worker know his weaknesses and strengths and making definite plans with him to overcome his defects and to make capital of his strengths.
2. Grievances can be prevented by letting the worker understand the basis for actions which may be taken in the future and by clearing up misunderstanding about past actions that have affected him.
3. The supervisor and the worker can be brought into closer personal relationship wherein each has a better understanding of the other, and the worker is made to feel that he is a person and not just a clock number.
4. Pent up emotions which may be reflected in acts of aggression towards management may be relieved by providing opportunity for rebuttal and talking out the situation." (3)

Application, Philosophy, Practice:

Merit rating will have greater productivity and validity if the procedure is seen as part of a total process of supervision, rather than an isolated and threatening item in a worker-supervisor relationship. The rating should not come as a "surprise" to the employee; the supervisor should be aware of the ratee's weaknesses and strengths and find ways of offering assistance over a period of time in advance of the rating period.

In this way the supervisor helps the employee become aware of his evaluation of his performance, and gives him the opportunity to learn what is expected of him. The supervisor should share his constructive criticism with the employee before the actual rating conference. The use the employee makes of direction, to enhance his performance, is also indicative of his value, attitude and merit.

Thus, the merit rating conference becomes a device to help the worker estimate his role—in a realistic sense—as a part of the total organization. The conference serves as a proper jumping off place for future progress on the job.

It is the experience of the writer that in most organizations, because of the pressure of just those daily tasks alone which require the attention and supervision of the foreman, group leader or department head, the supervisor who does the rating, the time allotted to the evaluation and to the conference is disproportionate to the importance of the merit rating so that both the company and the employee suffer as a consequence.

It is generally wise to schedule periodic conferences of the raters, to establish uniform yardsticks so that the same measurement scale is applied throughout the organization. Raters conferences of this sort tend to bring out, by active participation, discrepancies between one rater and another, the "easy" or "high" rater, as opposed to the "tough"

or "tight" or "low" rater. A ratee, known to more than one rater can be used as a comparison subject.

Raters should be conscious of the "halo effect", the tendency to permit one factor of the evaluation to influence other factors or traits of the individual being evaluated. The "personality kid" may or may not be a productive worker and the "personality" should not be permitted to becloud all other traits of the evaluation.

A little self-introspection on the part of the rater goes a long way too. The rater, thinking of himself as "having arrived" as a supervisor, no longer subject to the human frailties of mis-judgment or fallibility, can lose touch with the line, recalling only dimly "the days of his youth".

A rater might neglect to take into account personality differences between himself and his subordinates, those traits which do not in themselves affect the productivity of the employee but which do not exactly reflect a personality similarity between the rater and ratee. Doing things differently, for example, should not be confused with doing things wrong.

Rater's Training:

The training program for raters, which must include an analysis of the climate of the conference between rater and ratee, as an important portion of the overall schedule must include:

"1. Clarification of the aims and purposes of merit rating.
2. Instruction on the meaning of the traits or characteristics to be evaluated.
3. Instruction on the meaning of the points on the scale used.
4. Instruction on the avoidance of common pitfalls in rating, such as:
   a. Lack of objectivity (basing ratings on supposition, guesswork, emotional bias).
   b. Rating one trait in the light of ratings on other traits.
   c. Rating on the basis of general impressions.
   d. Rating on the basis of single dramatic incident.
   e. Restricting the spread of ratings.
5. Supervised practice and discussion of practice ratings made.
6. Instruction in how to use and interpret the ratings.
7. Periodic refresher training." (4)

It is not suggested that the foreman needs to become the equivalent of the university-trained psychologist, but rather that the foreman have some awareness of the social scene as it influences people and their productivity. The foreman should realize that each person is different from every other person, that while motivations are frequently the same for most people, the degree or manner in which people seek to achieve gratification or satisfaction is not the same. Discussion between rater and ratee, provided it is frank, sincere, and showing no hostility as an underlying feature, frank discussion on subjects other than the immediate job can help the job situation as well.

TABLE 1

Survey of Qualities in Use

(From a survey made by Life Office Management Assoc., Lytle, Charles Walter, Job Evaluation Methods, Ronald Press, New York, 1954, p. 348.)

No.	Hourly Employees	No. of Cos.	Salaried Employees	No. of Cos.
1	Quality of Work	40	Job Knowledge	26
2	Quantity of Work	38	Initiative	26
3	Dependability	24	Quantity of Work	23
4	Job Knowledge	21	Quality of Work	22
5	Cooperation	21	Dependability	19
6	Initiative	19	Judgment	18
7	Attitude	17	Cooperation	18
8	Safety Habits	16	Attitude	14
9	Attendance	14	Leadership	13
10	Working Conditions	12	Working Relations	12
11	Learning Ability	12	Learning Ability	12
12	Physical Conditions	10	Appearance	11
13	Adaptability	10	Personality	10
14	Personal Habits	9	Attendance	9

Merit Rating Format:

Too many people consider merit rating to be some elusive-intangible, the measurement of which is impossible, or at best, extremely difficult and very time consuming.

The exact format used in merit rating is not as important as most people seem to believe, provided the material is kept simple, direct, and free of ambiguity. A long, tedious evaluation form tends to lose sight of the purpose of the rating. Merit rating is a device which is employed to build a firm, but friendly, relationship. Merit rating should not be destructive in any event.

The format of a merit rating plan differs from organization to organization. As a general rule, a company selects those several traits which it deems most important and evaluates employees using just these. There may be, and this is desirable, a change in the selection of these traits when using them for factory personnel as opposed to office personnel. (It should be borne in mind that executives get rated too.)

The following Table 1 offers representative material on the frequency of use of the most widely used traits in merit rating:

Conclusion:

Merit rating, in the hands of supervisors who are trained and schooled in the recognition of what is to be accomplished, well-versed with the method of its application, and who are cognizant of the validity and reliability of the factors which are to be taken into account, merit rating in this scientific setting can serve to bring about a harmony of relationships which could not be achieved otherwise.

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2. Op cit, p. 21
3. Op cit, p. 23
4. Op cit, p. 32

Incentive by Chance? Part II

By Ralph W. Arboe

Chief Industrial Engineer, American Air Filter Company

The first article of this series proposed a plan of chance reward for individual production which, it was thought, might tap certain resources of human behavior for the purpose of stimulating individual productivity while avoiding many of the difficulties attendant upon the conventional incentives. Based on the belief that many labor difficulties are due to boredom and the lack of personal satisfactions in unskilled shop work, and on the defensiveness which results when individual workers face unfavorable comparisons under a conventional incentive system, the proposal offered a technique which skirted both of these dangers.

In essence, the plan created a lottery in which secret items of production, chosen at random, paid lump-sum rewards to the individual who chanced to complete the particular item. It was suggested that this plan could capitalize on the attractions offered by games of chance in general and could lead to individual workers attempting to improve their share of the prize money by increasing their own personal levels of production.

The application of this general principle to the American Air Filter organization by the Industrial Engineering Department brought to light other problems. To begin with, management, perceiving the need for a substantial staff to administer this program, balked at the expense. It was considered that a conventional incentive program would involve an identical expense, but management felt that the newness of the plan placed the administrative costs in a somewhat dimmer light.

It also became quickly apparent that many workers are not in direct competition with other workers and therefore unable to improve their chances to win someone else's prize money. These employees were typically found in a sequential chain of operation; their duties were not exactly duplicated by any other workers.

Faced with these difficulties, the Industrial Engineering Department developed the modification of the basic plan which is described in this article. Taking one of these groups of related and sequential operations as a guinea pig, they abandoned the concept of a production lottery and substituted for it a concept of the worker's total daily production (expressed as a numerical value), matching or exceeding a value selected at random as the basis of his chance reward.

Unit 1, as this group was called in the study, consisted of a sequence of 12 operations. The relationship of the elements in this unit is shown by the flow chart in Figure 1. Typical daily production for each of these elements (determined from production records) varied widely from element to element. It was assumed, since no incentive methods existed and no production standards had ever been established, that the existing level represented approximately 67 per cent of a "normal day's work" and that 200 per cent might reasonably represent an approximate physiological maximum.

If, for example, in the case of Operation No. 1 (with a mean daily output of 480 units) there were two lucky numbers, one ranging from 0 to about 600, the other ranging from 500 to 1440, the operator would, more often than not, receive the lesser reward and would infrequently earn the greater reward.

Despite the fact that the two sets of numbers for this one operation distributed in an orderly manner through the above ranges, it proved perfectly possible to concentrate the percentage of return at any level desired without

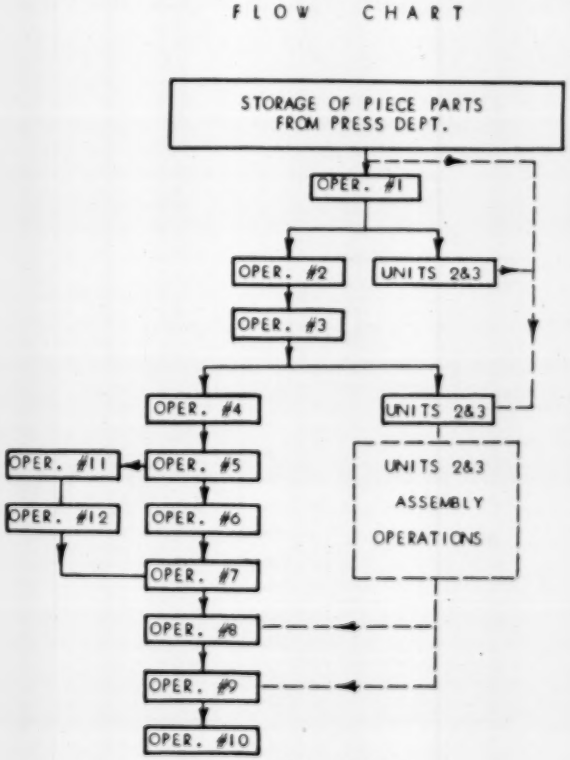

Fig. 1. Flow Chart, Unit 1.

TABLE 1

Operation No.	Daily Output	Lucky No. Range	
		1st No.	2nd No.
1	480	0–576	384–1440
2	480	0–576	384–1440
3	480	0–576	384–1440
4	120	0–144	96–360
5	240	0–288	192–720
6	240	0–288	192–720
7	160	0–192	128–480
8	240	0–288	192–720
9	480	0–576	384–1440
10	480	0–576	384–1440
11	48	0–58	38–144
12	48	0–58	38–144

damaging the workings of the system. The table of typical daily outputs for each of these operations and the total range covered by the two lucky numbers in each case is shown below in Table 1.

The rationale depends heavily on the effect on the worker of "near misses" with respect to the second (and larger) reward. Despite the fact that in the long run the relationship between the individual's level of productivity and the value of his total, long-time, chance reward will be highly consistent and highly correlated, there will still remain a large degree of day-to-day variation. Thus, on a particular day, as the result of an average performance the worker may win both awards, and conversely, on another day a really splendid effort may win him nothing at all.

But each day the worker faces the possibility that good fortune may yield him a double reward as a function of chance, and that the likelihood of this bonanza is increased in direct proportion as his production for that day is increased over the mean value shown in Table 1.

In the study, itself, a deck of 50 cards was prepared, each showing the 12 operations and a different set of lucky numbers for each operation. An example of one of these cards is shown in Table 2.

TABLE 2

Unit #1 Operations

Oper. No.	Description	Lucky	Nos.
1	Stencil Mach.	55	1035
2	Form Corners	1085	1277
3	Spotweld	783	910
4	Load Media	100	138
5	Crimp (use #4 No. Pcs.)	47	—
6	Cap Cell End	30	240
7	Insert Stiffeners	52	—
8	Arc Weld Latches	230	—
9	Paint	336	—
10	Pack	40	890
11	Special Size Mach. Cut-Off	—	—
12	Special Size Mach. Load.	48	103

LUCKY NUMBER AWARDS

First No.	Second No.
$1.00	$1.75

Fig. 2. Lucky Number Award.

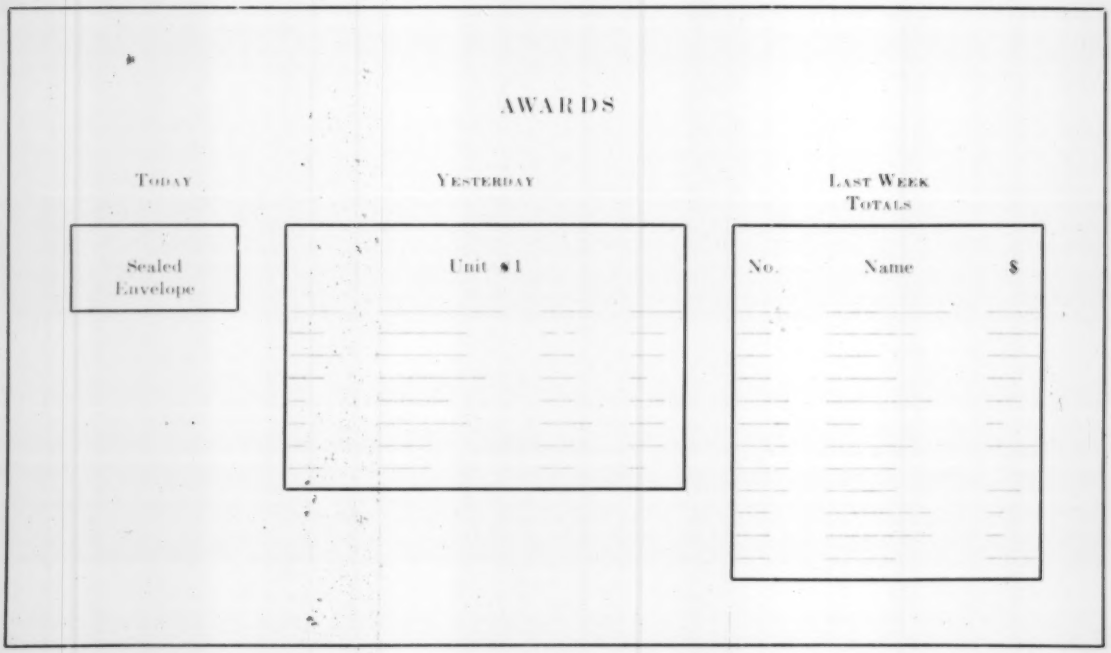

Fig. 3. Display Board for Posting Sealed Envelope, Results of Yesterday's Drawings and a Listing of Last Week's Awards.

At the end of the working day, one such card is drawn at random from the deck of 50 and posted on a special board prepared for that purpose. A second drawing also occurs at that point. This drawing determines the monetary value to be paid to the lucky numbers, so that the actual reward is a product of the two chance variables. A typical lucky number reward is shown in Figure 2.

The monetary values, in this case ranging from 0 to $3.00, can, of course, be pegged at any level desired.

The special display board, Figure 3, when the plan is in operation, will contain today's sealed envelope which is to be opened at the end of the day, the results of yesterday's drawings, and a published record of last week's awards to individuals. The drawing, it was felt, should be done by a representative of the employees, possibly a steward.

The results of the 15-day study of Unit 1 are shown in Table 3. A comparison of the actual award with the theoretical 100 per cent award demonstrates clearly that over a short period of time there may be substantial variations in the two values. It is held by the authors that this fact constitutes one of the primary advantages of the plan since it preserves the chance element upon which the program essentially depends.

During the study, the entire program, including the drawing of numbers and the tabulating of results, was administered by one supervisor who found that his daily expenditure of time averaged about two and one-half hours. From an administrative point of view, the Arbor plan is much more economical than the original proposal. Its defect is, of course, that it loses whatever value results from the worker's attempting to better his chances at the expense of his competing workers.

It shares with the original proposal, however, several advantages. One is that it obviates time studies and the setting of exacting standards. Another is that it largely removes the rewards from the realm of collective bargaining; and finally, it provides a game with which the employees can alleviate their boredom without harm to management's productivity needs.

TABLE 3

Unit #1 Dry Run Analysis 15 Days Operation

Opr.	Descriptive	Days Worked	Production Level	Actual Award	100% Award	180% Award
1	Stencil	10	44%	.75	2.75	7.20
2	Break	10	44%	0	4.70	11.15
3	Spotweld	9	47%	2.70	4.40	9.40
4	Loader	26	112%	17.04	21.45	34.50
5	Crimp	30	100%	6.80	10.00	23.70
6	Cap.	23	77%	1.60	5.50	15.15
7	Rods	30	112%	14.30	10.10	38.55
8	Arc Weld	7	58%	3.75	3.35	5.85
9	Paint	15	65%	3.00	5.60	13.30
10	Pack	10	63%	2.50	4.00	9.50
11	Manual Cut-Off	35	100%	7.00	8.70	19.95
12	Manual Loader	35	100%	23.90	17.15	43.65
Totals			Avg. 86%	83.34	97.70	231.90
Average total daily award				4.90	5.74	13.64
Average each worker daily award (17)				.33	.38	.91

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Why Invent a Profession

By James L. Schuler

Bureau of Ships, U. S. Navy Department

In the May-June 1955 issue of this Journal, Mr. Alvin Brown explained "How to invent a profession". The humor of this article was refreshing. But it touches only the fringe of a really fundamental human problem. I refer to the problem of why new professions are invented. Do we need new professions and, if so, why? Professions, like people, are born. They grow—they contribute—they become middle aged—they get old. Rarely do they die. But frequently they show signs of old age.

The subject of "Why invent a profession" covers many of the problems from toddling to tottering in professional growth. It explains the advent of such new professions as Value Engineering, Value Analysis, Statistical Analysis, Operations Research, Mathematical Programming and Industrial Engineering. It explains the advent of older professions such as Electronic Engineering, Electrical Engineering, Civil Engineering and Naval Architecture as well as Law and Medicine.

The dynamics of the life of a profession start with a need. This need is frequently the result of the mental rigor mortis of people in existing professions. The old profession will fail to fill a need because it is newer than the profession. The needs of society change even as society itself changes.

Along comes a man with a creative spark and a less-calcified attitude. He sees a need and notes the gap between existing professions. He conceives a solution and his one per cent inspiration is done. He begins to supply the ninety-nine per cent perspiration required to satiate the need. This creative man deserves a good deal of credit because he is the "spark plug". He invents a profession to do a job. It works well for a time.

Then, when everyone is aware of the need, these ideas filter down to the working level. They eventually become entombed in text books and are preached to the next generation. This generation, on the average, is average. If there had been no wheel, they could not have invented the wheel. If there had been no language, they could not have invented a language. If there had been no electricity, they could not have discovered electricity. They don't invent—they use. This relieves the new engineer because he couldn't re-invent the five basic machines. He can accept his inheritance. He can drink in the wisdom distilled from prior creative minds. If he is creative, he can create something new on the foundation of previous creations.

You cannot tell anyone how to invent a profession. Like all creative endeavors, only a few people are capable of real invention. These few don't need instruction. Conversely, all of the directions in the world won't help those who are not creative because you cannot teach people how to realize that a problem exists. The first symptom is a man banging his head against a problem. Soon he either learns to live with it or he sets out to change things. One tool for changing things is the invention of a new profession.

The crux of the discussion, therefore, is why not create within the old professions. Why invent a new profession? Why think up a new name? Why use new words? Because new words get old. Because old words are often spoken without clear thought behind them. Because a person has to think when he deals with a new term. New terms are used to denote a new facet of a problem. This is a tool used to fight the natural human tendency to enshrine the past. It is good to learn from yesterday but it is a grave error to worship it. So, knowing full-well that by tomorrow, today will be yesterday, the creative man sets out to right the wrong.

The creative engineer usually sets out to save some money. He is not really interested in the money for itself. Money is merely a convenient way of measuring. If he saves a dollar he is really saving a dollar's worth of human effort. This saving may reflect itself in a higher standard of living on a fuller, happier life. It will result in enhanced human value.

Time does not stand still. The process of aging goes on. The symptoms of advanced age are obvious in the older professions. Medicine and Law are good examples. By giving every sore thumb and broken toe nail a latin name, the medical student studies latin instead of how to cure diseases. A lawyer studies res adjudicata rather than the fundamentals of justice between humans. In short, the average professional man spends far too much time pawing over the dry bones of his profession when he should be thinking of ways to give it a blood transfusion.

When a creative individual brings forth a new idea he may integrate his approach into an old profession or he may decide to establish a new profession. In either case he should be embraced hospitably not derided or belittled. Every truly great man in history was considered radical because he was ahead of his time. But times change swiftly even if men do not.

As professional men, we should strive to keep our professions moving. We should neither deride nor fear new names, new languages or new ideas. If we must deride, then deride stagnation.

READER COMMENTS*

The Generalist

In R. L. Geiger's article "The Generalist", March–April issue of the JOURNAL, he highlights the fragmentation of knowledge that the ever-increasing number of specialists are producing. To counteract the confused mass of assorted facts, he shows how the "generalist begins to make order out of this star-ridden chaos". Geiger's observations are true for the extreme situation, the overall view of knowledge, but they do not cover the problem that confronts about all of us—to be both a specialist and a generalist at the same time.

We must all specialize and do something well to earn our daily bread. Such are the requirements of society that each person must be able to do one or several things to contribute to the workings of whatever type organization they are associated with. As an analogy one must move up in a tower of specialization, and improve the quality and character in that field and specialty that gives the individual his stamp of character, his *raison d'etre*.

But on the other hand, we must live on the wide plane of life, understand the total drama to know where our work fits in, to relate the special findings and techniques of our own field in their true position, to give meaning to our effort and make the results effective. The classic definition that a specialist knows everything about a subject, except where it fits, emphasizes the inadequacy of specialized work that is not related to other effort and tempered with its characterlogical limitation.

Thus we must do two contradictory things simultaneously—move upward as high as we can in a tower of specialization and, at the same time, move horizontally on the wide plane of life. To do both things well is the accomplishment of the complete man. *Alan J. Levy*

Author's Comments

I do not take exception to Mr. Levy's views regarding the role of the "Generalist". There may, in fact, be only a question of semantics separating us.

The generalist may equally be called an "Eclectic", in the sense that he selects what seems best from various sources. In his training he specializes in becoming a generalist, and this paradox is what makes the generalist so rare.

In my article I wrote about the generalist living shoulder deep in the everyday affairs of business. Unlike the natives of Lower Slobbovia he cannot be kept in a deep freeze. He must be able to climb above the level snowy plain into higher hills with wider vistas. To use another simile, he must resist being placed in a special cell whose walls are too high for him to look over. He must perceive the Gestalt pattern.

I do not believe that every John or Jonathan should be a generalist. Neither do I believe that everyman must become a specialist. Mr. Levy's "complete man" will not conform to a narrow categorizing. As Thoreau said, "let every man endeavor to *be* what he was made." *R. L. Geiger*

First Aid for Plant Layout

I would like to comment on the excellent article by Professor Smith, "First Aid for Plant Layout" in the January JOURNAL. Upon reading the article I felt that an immediate application of the technique in our plant may prove worthwhile.

Ours is not a process type layout and as the organization grew, stations were placed on a "space available" basis. The Travel Chart immediately brought to light a valuable change in our existing layout, but this change hampered further analysis on our existing Travel Chart information.

We found that 30% of our material handling was to a central inspection station and it became obvious that decentralization was worthwhile. One can tell from the chart data how many parts will go to each new inspection station but one does not know where parts will go after this station without compiling new data.

Since this problem will occur whenever decentralization takes place I suggest Professor Smith mention that a separate Travel Chart be made on any station (primarily light equipment) that may be decentralized. For instance, if Drill Press may be decentralized, enter into the chart I

CHART I. Parts passing through drill press station.

		GO TO		
		MILL	BURR	INSP.
COME FROM	MILL		3000	1000
	BURR	800		
	INSP.	1000	3000	

* "READER COMMENTS" is designed to provide a voice for discussion of recent articles and general issues. Please limit comments to 400 words.

while compiling main Travel Chart data. This will save going through thousands of routings, as we will be doing, should decentralization become a reality. *Paul E. Weiss*

Author's Comments

The problem to which Mr. Weiss refers in his letter is certainly a very real one which I have also encountered several times. It is certainly frustrating, as well as time-consuming, to search through the original data all over again when this is necessary because the data in each block is mixed, and it is impossible to tell where the parts will go after they reach the newly established station. It is also impossible to be sure which of the newly established stations should receive the parts (this disagrees with Mr. Weiss's statement) since the station that they would be sent to under the new system depends not only on where they have come from but, also, where they will go next.

This problem can perhaps be best illustrated by transposing the data provided by Mr. Weiss back into the form in which it would have appeared on the original travel chart. Chart 2 shows a simple transposition of this data:

CHART 2

FROM \ TO	MILL	BURR	DRILL	INSP.
MILL			1000 3000	
BURR			6000 800	
DRILL	800 1000	3000 3000		1000 6000
INSP.			3000 1000	

CHART 3

FROM \ TO	MILL	BURR	DRILL	INSP.
MILL			4000	
BURR			6800	
DRILL	1800	6000		7000
INSP.			4000	

The next chart (chart 3) shows how it would have actually appeared on the original travel chart:

It should be apparent that it would be *impossible* to reverse this process and go back to the data as Mr. Weiss shows it without reviewing all of the original routings.

In summary, this is an excellent suggestion wherever you think that decentralization might help. It is easier to collect this data on one pass rather than to run again through a large number of routings. Eventually, we may have routings recorded on IBM cards or some other method that would facilitate obtaining the desired information more efficiently. *W. P. Smith*

Perfection in Engineering?

We seem to have many articles on what is wrong with all the existing systems of Incentives, Performance Rating, and Pre-determined Time Standards. There seems to be all manner of concern that present day methods and systems are unscientific and that two Engineers from different plants can't rate within ±5%. They present well worded arguments backed by much statistical test data to prove their points.

Now all this information is very good and certainly makes a worthwhile addition to the engineer's background and is helpful in aiding in a more realistic approach to one's appreciation of some of the counter-claims of unions. Yet many of the articles are presented in such a gloomy manner that they distort the whole picture and instead of being useful as an added increment of positive information they are presented as laments of the sad situation of the "science that isn't a science".

Any practicing Engineer, who is at all objectively perceptive, will readily admit all Therblig relationships are not + or − or strictly linear, and he will usually likewise agree that it's not systems, but proper application that makes success—good judgment is most important. And the same engineer will not claim that his solution or evaluation of a problem is going to be the same as anyone else's.

Why does this lack of consistency in application of methods, results and relationships prove to the researchers that Industrial Engineers are unscientific or pseudo-engineers, and their work a mere matter of applied personal opinion and prejudice? Why is the wide use of judgment looked down upon? Any other field of Engineering is allowed, even encouraged, to seek answers to its problems through many avenues, and the many answers to the same problem are not considered as failings. Yet by its scope, Industrial Engineering is the most complex and extensive, concerning itself with the most involved and dynamic of systems, the human being and his interactions and reactions in the economic order. And still the Industrial Engineer is supposed to come up with "constant" answers.

Just for comparison, let us take an example from a relatively complicated field of conventional engineering: the problem of airframe configuration and control surface layout for an airplane to operate from the sub-sonic to the super-sonic range. It will be necessary to overcome the stresses of the sonic transition and provide stability at all times.

What is the answer? There is no single answer; the varied models that come from our aircraft industry show us that

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they range from Delta wing to thin narrow wings, from the needled nose thin fuselage to the open front "bulging cigar" type. So far, I haven't heard any of these flying answers called unscientific or the designers accused of not using good engineering techniques because of the diversity of conclusions that they reached after reviewing the *same* problem.

Many of the features of these "answers" above are different because the engineers in their respective judgments consider certain aspects of the problem more important, and still others are arrived at in the light of new materials and methods becoming available.

In our own problems, why should Engineer #1 from New England come up with the same answer as Engineer #2 in Texas even though both are working on the same problem, i.e., rating workers on a specific job? The conditions are different, the workers' backgrounds are different, management and union relations are different. Certain features are going to be emphasized, motives are going to be variously stimulated. Therefore, certain aspects of performance are going to be stressed in one location but not in another. And what is rating but an evaluation of performance factors. Thus, asking the Engineers to change positions and be consistent is most absurd. They must be given time to adjust their "systems" to meet the new aspects of the problem. *Richard L. Giovanoni, U.S. Army*

RECENT READABLES*

AUTOMATION

"The Transfer Machine Opens New Production Horizons," M. O. Cross, Jr., *Mechanical Engineering*, April, 1955.

Describes use of tool programming unit which schedules tool operations of a particular machine and then shuts down machine for a tool change. Discusses type of management needed under technology required for automation.

FORMS CONTROL

"The New Science of Records Management," R. A. Schiff and A. Barcan, *Business Review*, September, October, 1954.

The principles of establishing a sound forms control program. Case histories of various companies. The authors are associated with the National Records Management Council.

"A Forms Control Program," A. W. Clark, *Office*, May 1955.

An insurance company reports on their detailed program for controlling forms. Over 1000 different forms are constantly modified, replaced, eliminated or consolidated.

INVENTORY CONTROL

"Inventory Control System in a Steel Warehouse," R. Neumaier, *Office*, May 1955.

Describes the steps taken by one company to improve accuracy of inventory data through an effective control system. The system was specifically designed for their own company after a survey of thirty-nine (39) similar companies revealed no pattern of consistency.

JOB EVALUATION

"A New Method of Job Evaluation," E. N. Hay and O. Purues *Personnel*, July 1954.

Describes the Guide Chart Profile Method for ranking and evaluating jobs. This method is a modification of the factor-comparison method.

LINEAR PROGRAMMING

"Methods Engineering," H. B. Maynard, *Mechanical Engineering*, April 1955.

Report on talk delivered by Mr. Maynard at Engineer's Club in New York. Discusses linear programming and cites a few examples. Mentions MTM and Master Training Concept. This is an abstract, not the complete talk.

MATERIALS HANDLING

"Materials Handling Trends," J. B. Bright, *Mechanical Engineering*, April 1955.

A brief extract of a complete report on Materials Handling delivered at a meeting of the Institution of Mechanical Engineers of Great Britain. The paper covers five fields: (1) the significance of materials handling in economic life; (2) the objective of materials handling; (3) how American industry is organizing for materials handling; (4) methods of solving problems; (5) significant trends in materials handling.

"Automated Warehousing System," J. J. Jaklitsch, Editor of "Briefing the Record" section, *Mechanical Engineering*, May 1955.

Case history of the application of automatic devices to the warehousing problem. Describes use of conveyors along with electronic controls to provide for the advantages of "bulk picking" while retaining the desirable features of conventional "order picking."

"Making Management Listen," J. R. Bright, *Modern Materials Handling*, July 1955.

Outlines the procedure to follow in developing an effective materials handling program. The author particularly stresses the importance of organizing an orderly program for solving plant material handling problems. "Too Many Material Handling Men Try to Sell Objectives Rather Than Specific Plans."

"How to Select the Best Pallet Pattern," C. J. Heinrich & J. K. Akrep, *Modern Materials Handling*, July 1955.

Explains the use of a dual-purpose chart developed by the

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* This is the first in a feature series designed to inform JOURNAL readers of the many articles and books pertaining to Industrial Engineering which are being published in periodicals. Recent Readables will not analyze, interpret, nor criticize, but rather will list under general subjects articles which might be of interest to our readers. Each listing will include title, author, and source along with a very brief description of the subject matter. The Editor hopes that Recent Readables will offer a service in which JOURNAL readers are interested. Let us hear from you—if you run across anything you think would be interesting to others, send it in.

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"Materials Handling, 1855–1955," *Iron Age*, June 1955.

The 100th anniversary issue of *Iron Age* has an excellent section devoted to the history of material handling. The article is divided into three sections: The Past; The Present; and The Future. Of particular interest are the old photographs of early material handling devices.

"How to Get More for your Material Dollar," Pg. 95, *Factory Management & Maintenance*, July 1955.

This is a report on a survey made of an "average industrial community." Thirty-eight of 44 plants in the Bridgeport, Conn. area were interviewed concerning handling problems. Outlines ten steps for reducing handling costs and pictorially describes 37 handling ideas used by the plants surveyed.

METHODS

"Methods Planning—When, Where, How?," R. W. Fairbanks, *Office*. February and March 1955.

A two part article which thoroughly discusses the planning and installation of methods improvement program. Outlines factors that should be considered and discusses personnel selection within the framework of the resulting methods group.

OPERATIONS RESEARCH

"Operations Research: Scientific Approach to Management," M. Goland & E. Koenigsberg, *Chemical Week*, May 21, 1955.

A comprehensive article written for executives to inform them of just what Operations Research is. Briefly outlines typical problems that are solved by Linear Programming, Gaming Theory, Monte Carlo Methods & Queuing Theory. Describes how to get an O. R. team started in your plant.

PLANT LAYOUT

"How to Evaluate Alternate Layouts," Editor, *Factory Management & Maintenance*, February 1955.

Practical techniques used by layout engineers in evaluating alternative layout designs. Factor analysis and point values are used as aids in making final decisions.

PRODUCTION CONTROL

"Photocopying Speeds Production Control," H. R. Wilson, *Office Management*, February 1955.

North American Aviation Company's use of photocopying to control production scheduling. The new system has resulted in production not missing a schedule in over one year of operation by simplifying the necessary paperwork.

QUALITY CONTROL

"Continuous Sampling Inspection," A. L. MacLean, *Factory Management and Maintenance*, February 1955.

Case history of random sampling applied to an inspection function which allows production flow to continue uninterrupted past inspectors. Control charts are used to make decisions involving process changes.

"A Trade Unionist Looks at Quality Control," W. Gomberg, *Industrial Quality Control*, November 1954.

Mr. Gomberg's analysis of the statistical validity of time studies and standard data systems. The author states that these systems "are a rather poor empirical attempt to develop modus vivendi, upon which both management and labor can reach agreement."

SCHEDULING

"Maintenance Schedule Board," H. T. Lincoln, *Factory Management and Maintenance*, April 1955.

How the Jones & Laughlin Steel Corporation utilizes a Gantt chart for scheduling and controlling maintenance work. A case history which does not go into detail.

WAGE INCENTIVES

"Is Your Incentive Plan Headed for Success—Or Failure?" Pg. 128, *Factory Management and Maintenance*, May 1955.

This is a report on a survey of 100 companies made by the Methods Engineering Council. The results reported in this article can be used to compare your company's incentive plan to systems utilized by other companies.

WORK MEASUREMENT

"How Many Time Study Readings to Take," G. Nadler, *Factory Management and Maintenance*, February 1955.

Explains the use of a nomograph in determining the number of elemental time observations to take. Points out how nomograph can spot trouble and indicate course of action to follow.

"How Ethyl Cut Maintenance Costs," M. C. Hudgins, B. D. Harrison and S. A. D'Armond, *Petroleum Processing*, April 1955.

Generally outlines the role of time studies to measure maintenance performance for cost control and scheduling.

"Methods: Is Machine Boss?," G. J. McManus, *Iron Age*, May 19, 1955.

Short article which discusses study made by Dunlap & Associates involving work diversification as opposed to work simplification. Cites a few cases where production was increased as a result of allowing worker to assume increased responsibilities.

"A Clerical Work Measurement Program," R. W. Fairbanks, May 1955, *Office Management*.

The mechanics of installing a work measurement program leading to clerical standards used for incentives. The author is associated with a management consulting firm.

"A Clerical Cost Control System Using Standard Time Data," E. W. McNamara, *Office*, June 1955.

Outlines the Bassick Company's development and installation of a clerical budget, based on a standard data system, which is used as a tool to determine the operating efficiency of departmental functions. The objectives of the plan are: to control clerical costs by maintaining proper staffing through the use of standard data.

"Better Way to Figure Fatigue," E. H. Merrill, Jr., *Factory Management and Maintenance*, June 1955.

Dodge Manufacturing Company's formula for determining

job fatigue allowances. Four major factors considered are physical effort, mental effort, idle time and monotony. Lighting and ventilation are job conditions covered by their job evaluation system. Bench mark jobs are used as a guide in determining fatigue for over 130 jobs—foundry, core room, machine shop, steel shop, assembly department and warehouse.

"Stoop or Bend," B. Davidson, *Colliers*, May 27, 1955.

Describes the use of the Lauru Platform for measuring effort requirements for elements of work. The article states that the Lauru Platform is so sensitive that it can measure your heartbeat and even the muscular activity of a mouse walking across it. The platform has been used in a number of instances to solve industrial fatigue problems involving bricklaying, piling 50 lb. bags, reducing typist fatigue, body positions for lifting heavy weights, etc. Dr. Lillian Gilbreth in commenting on the Lauru Platform states, "Until now we've been relying purely on guesswork to get maximum production out of workers with less fatigue. Now at least we can replace judgement with facts."

"Short Cut to Low-Cost Maintenance," S. G. Carney, *Factory Management and Maintenance*, June 1955.

Describes Dow Chemical's work order estimating system for controlling maintenance expenditures. The author states that work measurement based on elemental time studies is not practicable in maintenance except for highly routine operations. Dow uses historical and experience data to estimate work orders for scheduling and cost control.

WORK SAMPLING

"Work Sampling Sold Safety For Us," J. Maguire, *Factory Management and Maintenance*, February 1955.

Case History of one company's use of work sampling techniques to lower accident rate. Non-technical.

"Time For a Time Utilization Survey," F. S. Macomber, *Factory Management and Maintenance*, May 1955.

The application of "work logging" and the work sampling technique to determine maintenance manpower utilization. These studies can result in increasing maintenance efficiency through reducing delays and lost time. Twenty-four ways to eliminate time wastage in maintenance are listed. These twenty-four suggestions were developed as a result of time-utilization studies made by the A. T. Kearny & Company, Management Consultants.

"A Short Cut to Fact Finding," M. J. Mandel, *Dun's Review and Modern Industry*, May 1955.

Describes in simple terms the fundamental statistical principles that are used to gather facts. The article explains some of the highlights of sampling: what it is; how it works; wherein comes its power; how accurate are its results; and what risks are taken by using them.

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WORK SIMPLIFICATION

"Methods Programs Aren't Restricted To Large Offices," R. C. Weisselbeeg, *Office Management*, May 1955.

Step by step procedure for instituting work simplification in office work. Does not go into details but generally outlines broad functions of office methods.

"Work Simplification Training," L. Stemp, *Plant Engineering*, January 1955.

Lists courses utilized for training employees, outlines a typical training program and includes case histories of results achieved by various companies.

BOOKS

Bibliography on Queuing Theory by Vera Riley, Operations Research Office, The Johns Hopkins University, Chevy Chase, Maryland, 1955, 27 pages.

A rather complete listing of literature pertaining to Queuing Theory. Available from the Author, Operations Research Office, 1700 Connecticut Ave., Chevy Chase, Maryland.

The Guaranteed Annual Wage & Business Stabilization—A Bibliography, Prepared by the W. E. Upjohn Institute for Community Research, Listings Selected by Henry C. Thole and Charles C. Gibbons, June 1955.

Single copies available without charge from the institute, 709 South Westnedge Avenue, Kalamazoo 44, Michigan.

"*Motion and Time Study—Principles and Practices*," by M. E. Mundel, Second Edition, 1955, Prentice-Hall, Inc., New York, 575 pages.

Dr. Mundel's revised edition retains the desirable features of his previous edition with the addition of new material. New Chapters have been added: Work Activity Analysis, Cyclegraphic Analysis, Work Measurement, Introduction to Time Study, Effort Rating in Direct Time Study, Basic Data for Synthesized Time Standards, and Statistical Time Standards.

"*A Trade Union Analysis of Time Study*," By William Gomberg, Second Edition, 1955, Prentice-Hall, Inc., New York, 318 pages.

It is encouraging and gratifying to see this controversial book again in print. Dr. Gomberg has included current materials in his revision. His treatment of time study theory and practice is critical and thought provoking—and should be studied by every individual concerned with work measurement.

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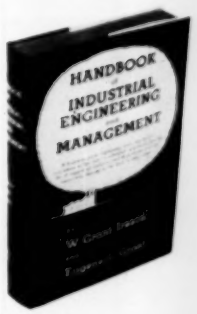

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